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EFFECTS OF VARIOUS CENTER-FIN AND TIP-FIN ARRANGEMENTS ON AERODYNAMIC CHARACTERISTICS OF A MANNED LIFTING ENTRY VEHICLE FROM MACH NUMBERS 1.50 TO 2.86

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Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1966

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To UNCLASSIFIED

By authority of STAR Date 12-31-70
V. 8 No. 2 Blm 3-12-71

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GROUP 4
Downgraded at 3 year intervals;
declassified after 12 years

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EFFECTS OF VARIOUS CENTER-FIN AND TIP-FIN ARRANGEMENTS ON AERODYNAMIC CHARACTERISTICS OF A MANNED LIFTING ENTRY VEHICLE FROM MACH NUMBERS 1.50 TO 2.86*

By James F. Campbell and Lloyd S. Jernell
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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel at Mach numbers from 1.50 to 2.86 to determine the effects of various center-fin and tip-fin arrangements on the aerodynamic characteristics of the negative-cambered HL-10 manned lifting entry vehicle. Some stability and control data were also obtained on the symmetrical configuration, HL-11. The results of the investigation indicate that roll-out of the tip fins leads to an increase in longitudinal stability. Tip-fin toe-in increases longitudinal stability and generally increases directional stability. Area added to the top of the center fin has considerably more effect on directional stability than area added to the forward portion has. The HL-10 has greater values of pitching-moment coefficient at zero angle of attack and lesser values of lift coefficient at zero angle of attack than does the HL-11 with little change in longitudinal stability; only small differences exist in the directional and lateral stabilities of these two models.

INTRODUCTION

The National Aeronautics and Space Administration is currently conducting investigations of manned lifting entry vehicles capable of horizontal landing. One configuration, designated HL-10, is presently being investigated at the Langley Research Center and results of some of the studies may be found in references 1 to 8. One of the problems associated with the HL-10 (which employs a negatively cambered flat-bottom body) has been the attainment of directional stability at operational angles of attack in the lower supersonic speed range. Some of the directional stability studies are reported in references 7 and 8 and the present paper is a continuation of the study of this problem. Several center and outboard vertical-tail arrangements have been investigated in various combinations. In addition, a limited amount of work was devoted to a similar noncambered configuration, designated HL-11.

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*Title, Unclassified.

The investigation was performed in the Langley Unitary Plan wind tunnel at Mach numbers from 1.50 to 2.86 for a constant Reynolds number based on body length of 2.13×10^6. The angle-of-attack range was approximately 0° to 40° and the angle of sideslip was varied from about -4° to 8°.

SYMBOLS

The longitudinal and lateral coefficients are referred to the stability and body axis systems, respectively. The longitudinal locations of the moment centers for both the HL-10 and HL-11 configurations was 53 percent of the body length aft of the nose. The vertical locations are shown in figure 1.

Measurements for this investigation were taken in the U.S. Customary System of Units. Equivalent values are indicated herein parenthetically in the International System (SI) in the interest of promoting use of this system in future NASA reports. Details concerning the use of SI, together with physical constants and conversion factors, are given in reference 9.

b	body reference span, 10.310 in. (26.187 cm)
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_{L_o}	lift coefficient at zero angle of attack
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
C_{l_β}	effective dihedral parameter, $\frac{\Delta C_l}{(\Delta\beta)_{0^\circ \text{ and } 3^\circ}}$, per deg
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$
C_{m_o}	pitching-moment coefficient at zero angle of attack
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_{n_β}	directional stability parameter, $\frac{\Delta C_n}{(\Delta\beta)_{0^\circ \text{ and } 3^\circ}}$, per deg
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{Y_β} side-force parameter, $\frac{\Delta C_Y}{(\Delta\beta)_{0^\circ \text{ and } 3^\circ}}$, per deg

l length of body, 16.00 in. (40.640 cm)

L/D lift-drag ratio

$(L/D)_{max}$ maximum lift-drag ratio

M free-stream Mach number

q free-stream dynamic pressure, lb/ft^2 (N/m^2)

r radius, in. (cm)

S reference planform area, 0.63440 sq ft (0.05894 sq m)

x,y,z coordinates defining model surface

X,Y,Z body-axis coordinate system

α angle of attack referred to model reference line, deg

β angle of sideslip referred to model center line, deg

δ_e deflection angle of elevon, positive when trailing edge is down, measured relative to model aft lower surface, deg

ϵ toe-in angle of tip-fin outer surface, measured in X,Y plane, deg (referenced to plane of symmetry)

ϕ roll-out angle of tip-fin outer surface, measured in plane perpendicular to fin outer surface and body lower aft surface, deg

APPARATUS AND TESTS

Model

Drawings of the models of the HL-10 and HL-11 are shown in figures 1(a) and 1(b), respectively. Coordinates of the body surfaces of the respective models are provided in tables I and II. The two configurations differ primarily in the amount of lower surface camber. Each is of delta planform, with a leading-edge sweep angle of 74°. Drawings of the various interchangeable center- and tip-fin arrangements are presented in figure 1(c). The toe-in and roll-out angles of the outer surfaces of the tip fins are listed in table III. The I-series fins differed only in the amount of toe-in and roll-out. It will be noted that fins I_3 and I_4 have approximately the same average (right and left) values of roll and toe. However, an error in the construction of the I_3 fins resulted in left- and right-fin roll-out angles of 7.8° and 9.1°, respectively. The questionable effects of this magnitude of roll-out asymmetry led to the construction of the I_4 fins.

Tunnel

The investigation was conducted in the low Mach number test section of the Langley Unitary Plan wind tunnel, which is of the variable-pressure, return-flow type. The test section is 4 feet (1.22 m) square by approximately 7 feet (2.13 m) in length. The nozzle is of the sliding-block type, which permits a continuous variation of Mach number from about 1.5 to 2.9.

Test Conditions

The test conditions for the configurations were as follows:

Mach number	Stagnation temperature		Stagnation pressure	
	$^{\circ}$F	$^{\circ}$K	psf	kN/m^2
1.50	150	339	890	42.6
1.80	150	339	976	46.8
2.16	150	339	1140	54.6
2.86	150	339	1640	78.5

Reynolds number based on body length was 2.13×10^6 for these conditions. The dewpoint was maintained below -30° F (239° K) to assure negligible condensation effects in the test section. The angle-of-attack range was from approximately 0° to 40°; the angle of sideslip varied from about -4° to 8°.

Measurements

Aerodynamic forces and moments were measured by means of a sting-supported, six-component, electric strain-gage balance mounted within the body. Measurements at the highest test angle of attack at $M = 1.50$ may be affected by shock reflection.

Corrections

The angles of attack and sideslip have been corrected for tunnel flow misalinement and model support system deflection due to aerodynamic load. Drag data are measured values and have not been corrected to free-stream conditions at the model base.

Accuracy

The accuracies, based on instrument calibrations and data repeatability, are as follows:

C_D	±0.001
C_L	±0.004
C_l	±0.0002
C_m	±0.0004
C_n	±0.0002
C_Y	±0.001
M	±0.015
α, deg	±0.10
β, deg	±0.10

FIGURE PRESENTATION

The data presented in the following figures were obtained for the model with zero elevon deflection, unless otherwise noted:

Figure

Longitudinal characteristics of HL-10:

Center fins E and E_2 with tip fins P_1 2

Center fins E, E_1, and E_2 with tip fins I_2 3

Tip fins I_1 and I_2 with center fin E_2 4

Tip fins I_3 and I_4 with center fin E_2 5

Tip fins D-1, P_1, and I_4 with center fin E_2 6

Longitudinal characteristics of HL-10 (center fin E_2) and HL-11 (center fin E) with D-1 tip fins 7

Longitudinal characteristics of HL-11:

Center fin E and tip fins D-1, $\delta_e = 0^{\circ}$ and -30° 8

Basic sideslip characteristics of HL-10:

Center fin E and tip fins P_1 9

Center fin E and tip fins I_2 10

Center fin E_1 and tip fins I_2 11

Figure

Center fin E_2 and tip fins P_1 12
Center fin E_2 and tip fins D-1 13
Center fin E_2 and tip fins I_1 14
Center fin E_2 and tip fins I_2 15
Center fin E_2 and tip fins I_3 16
Center fin E_2 and tip fins I_4 17

Basic sideslip characteristics of HL-11:
Center fin E and tip fins D-1, $\delta_e = 0^\circ$ 18
Center fin E and tip fins D-1, $\delta_e = -30^\circ$ 19

Directional and lateral stability derivatives of HL-10:
Center fins E and E_2 with tip fins P_1 20
Center fins E, E_1, and E_2 with tip fins I_2 21
Tip fins I_1 and I_2 with center fin E_2 22
Tip fins I_3 and I_4 with center fin E_2 23
Tip fins D-1, P_1, and I_4 with center fin E_2 24

Directional and lateral stability derivatives of HL-11:
Center fin E and tip fins D-1 25

RESULTS AND DISCUSSION

Longitudinal Characteristics

The longitudinal characteristics for the HL-10 model with any of the center fins (figs. 2 and 3) are similar throughout the angle-of-attack and Mach number ranges. Increasing tip-fin roll-out angle, however (for fins I_2 and I_1), leads to an increase in lift-curve slope and stability level with only a small effect on $(L/D)_{max}$ (see fig. 4). Comparison of the data of figures 4 and 5 shows that increasing tip-fin toe-in angle (for fins I_4 and I_2) leads to an increase in stability level. Other than a small decrease in minimum drag coefficient, the inaccuracies of construction of the I_3 tip fins had little effect on the longitudinal characteristics of the model compared with the model incorporating the I_4 tip fins (fig. 5). Data presented in figure 6 show that the configuration with D-1 tip fins develops more lift and has a greater stability level than the configurations with the P_1 and I_4 fins, even though the D-1 fin is considerably smaller. This condition, of course, is due to the greater roll-out and toe-in angles of the D-1 tip fin. A comparison of the data of figure 6 with that of figure 4, however, shows that I_1 tip fins, with an almost comparable roll-out angle to the D-1 fin and with substantial toe-in angle, leads to greater values of lift coefficient and slightly greater stability levels than those noted for D-1 tip fins.

A comparison of longitudinal characteristics of the HL-10 configuration with D-1 and E_2 fins and the HL-11 configuration with D-1 and E fins is shown in figure 7. These data show that, as would be expected, the HL-10 has greater C_{m_o} and less C_{L_o} than does the HL-11 with little difference noted in stability level or lift-curve slope for the two models. The data also indicate that the HL-10 and HL-11 have essentially the same maximum values of L/D, although the angle of attack for maximum lift-drag ratio varies from about 24° (for HL-10) to about 17° (for HL-11).

Effects of the E center fin and D-1 tip fins on the pitch characteristics of the HL-11 model are shown in figure 8. These data show a slight increase in C_{m_o} due to the center fin with little or no change in longitudinal stability; the D-1 tip fins do not materially affect C_{m_o} although they do lead to an increase in stability level. An elevon deflection of -30°, also illustrated in this figure, is seen to be effective in producing pitch throughout the test angle-of-attack and Mach number ranges, although there is the expected decrease in effectiveness with increase in Mach number.

Lateral Characteristics

The basic lateral characteristics in sideslip for various tip-fin and center-fin combinations on the HL-10 configuration are presented in figures 9 to 17. Generally, the yawing-moment-coefficient variation with angle of sideslip is nonlinear at the higher test angles of attack at $M = 1.50$. Increase in Mach number leads to relatively linear yawing-moment data through the test angle-of-attack range. The variation of rolling-moment coefficient with angle of sideslip is very linear at all Mach numbers and angles of attack. Yawing- and rolling-moment data for the HL-11 configuration with $\delta_e = 0^\circ$ (fig. 18) are linear at all test conditions; deflection of the elevon to -30°, however, leads to nonlinearity of the curves for both C_n and C_l data plotted against angle of sideslip, primarily at $M = 1.50$ (fig. 19).

The HL-10 configuration with center fin E_2 has noticeably greater directional stability and positive effective dihedral than does the model with center fin E at all test angles of attack and Mach numbers (fig. 20). This condition, of course, may be attributed to the greater side force, in turn, due to the larger size of center fin E_2. The data of figure 21 indicate that although there is an increase in directional stability and positive effective dihedral due to the added area of center fin E_1, the added area in this location is not nearly as effective as the added area at the top of the fin E_2.

Data of figure 22 show an increase in directional stability for the I_2 fins compared with the I_1 fins. Results from reference 8 have shown that a decrease in tip-fin roll-out angle leads to decreases in C_{n_β}; therefore, the small increase in toe-in angle for the I_2 fins over that for the I_1 fins has not only offset the adverse effects of decreased roll-out angle on C_{n_β}, but has also led to increases in C_{n_β}. The decrease in effective dihedral is primarily the result of the decrease in roll-out angle between fins I_1 and I_2, toe-in angle having little effect on C_{l_β}.

Comparison of data of figures 22 and 23 shows an increase in C_{n_β} with increase in tip-fin toe-in angle (fins I_4 and I_2). The model with the P_1 tip fins generally has the higher levels of directional and lateral stability throughout the angle-of-attack and Mach number ranges (fig. 24). The directional and lateral stability of the HL-11 configuration (fig. 25) is about the same as that for the HL-10 configuration at all test angles of attack and Mach numbers. This condition may be noted by comparing figures 24 and 25 and giving due consideration to the differences in stability level obtained between the E and E_2 center fins on the HL-10 model.

CONCLUSIONS

An investigation has been performed on two models of a manned lifting entry vehicle at Mach numbers from 1.50 to 2.86. These studies were directed toward assessing the stability characteristics of the models with several center-fin and tip-fin arrangements. The results of this investigation indicate the following conclusions:

1. Roll-out of the tip fins leads to an increase in longitudinal stability.

2. Tip-fin toe-in increases longitudinal stability and generally increases directional stability.

3. Area added to the top of the center fin has considerably more effect on directional stability than area added to the forward portion has.

4. The HL-10 has greater values of pitching-moment coefficient at zero angle of attack and lesser values of lift coefficient at zero angle of attack than does the HL-11 with little change in longitudinal stability; only small differences exist in the directional and lateral stabilities of these two models.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 21, 1966.

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TABLE I.- ORDINATES DEFINING CROSS-SECTIONAL SHAPE OF HL-10 WITHOUT TIP FINS

x/l = 0.042

z/l	y/l
0.0541	0
.0532	.0083
.0503	.0167
.0441	.0250
.0375	.0306
.0333	.0338
.0250	.0390
.0167	.0431
.0083	.0459
0	.0476
-.0536	0

x/l = 0.083

z/l	y/l
0.0681	0
.0668	.0083
.0637	.0167
.0579	.0250
.0502	.0333
.0417	.0392
.0330	.0444
.0250	.0487
.0167	.0521
.0083	.0547
0	.0568
-.0083	.0585
-.0167	.0596
-.0752	0

x/l = 0.125

z/l	y/l
0.0737	0
.0729	.0083
.0702	.0167
.0660	.0250
.0594	.0330
.0505	.0417
.0417	.0477
.0333	.0528
.0250	.0571
.0167	.0604
.0083	.0632
0	.0656
-.0083	.0675
-.0167	.0691
-.0250	.0704
-.0333	.0714
-.0904	0

x/l = 0.167

z/l	y/l
0.0771	0
.0763	.0083
.0744	.0167
.0712	.0250
.0664	.0333
.0597	.0417
.0512	.0500
.0417	.0565
.0333	.0618
.0250	.0664
.0167	.0701
.0083	.0732
0	.0757
-.0083	.0778
-.0167	.0796
-.0250	.0811
-.0333	.0823
0.0417	.0833
-.0500	.0840
-.1026	0

x/l = 0.208

z/l	y/l
0.0792	0
.0787	.0083
.0772	.0167
.0747	.0250
.0712	.0333
.0664	.0416
.0592	.0500
.0517	.0583
.0417	.0656
.0333	.0713
.0250	.0760
.0167	.0800
.0083	.0833
0	.0860
-.0083	.0882
-.0167	.0902
-.0250	.0919
-.0333	.0933
-.0417	.0946
-.0500	.0955
-.0583	.0962
-.1126	0

x/l = 0.250

z/l	y/l
0.0807	0
.0803	.0083
.0792	.0167
.0773	.0250
.0748	.0333
.0712	.0417
.0666	.0500
.0606	.0583
.0527	.0667
.0458	.0721
.0417	.0754
.0333	.0811
.0250	.0862
.0167	.0902
.0083	.0937
0	.0965
-.0083	.0990
-.0167	.1011
-.0250	.1027
-.0333	.1044
-.0417	.1057
-.0500	.1067
-.0583	.1076
-.0667	.1083
-.1205	0

x/l = 0.292

z/l	y/l
0.0817	0
.0814	.0083
.0807	.0167
.0794	.0250
.0774	.0333
.0750	.0417
.0715	.0500
.0672	.0583
.0617	.0667
.0546	.0750
.0500	.0789
.0417	.0858
.0333	.0918
.0250	.0969
.0167	.1010
.0083	.1044
0	.1072
-.0083	.1098
-0.0167	0.1119
-.0250	.1137
-.0333	.1156
-.0417	.1170
-.0500	.1182
-.0583	.1192
-.0667	.1198
-.0750	.1202
-.1268	0

x/l = 0.333

z/l	y/l
0.0820	0
.0818	.0083
.0813	.0167
.0803	.0250
.0789	.0333
.0771	.0417
.0747	.0500
.0716	.0583
.0677	.0667
.0627	.0750
.0564	.0833
.0485	.0917
.0417	.0968
.0333	.1027
.0250	.1078
.0167	.1119
.0083	.1152
0	.1179
-.0083	.1204
-.0167	.1227
-.0250	.1250
-.0333	.1267
-.0417	.1282
-.0500	.1296
-.0583	.1306
-.0667	.1317
-.0750	.1321
-.1312	0

x/l = 0.375

z/l	y/l
0.0821	0
.0820	.0083
.0816	.0167
.0809	.0250
.0799	.0333
.0783	.0417
.0766	.0500
.0744	.0583
.0714	.0667
.0679	.0750
.0633	.0833
.0576	.0917
.0503	.1000
.0415	.1083
.0333	.1136
.0250	.1187
.0167	.1229
.0083	.1262
0	.1292
-.0083	.1315
-.0167	.1337
-.0250	.1358
-.0333	.1377
-.0417	.1394
-.0500	.1408
-.0583	.1420
-.0667	.1429
-.0750	.1437
-.0833	.1442
-.1334	0

x/l = 0.417

z/l	y/l
0.0814	0
.0813	.0083
.0811	.0167
.0805	.0250
.0797	.0333
.0786	.0417
.0772	.0500
.0755	.0583
.0733	.0667
.0706	.0750
.0674	.0833
.0633	.0917
.0582	.1000
.0517	.1083
.0437	.1167
.0375	.1211
.0333	.1241
.0250	.1296
.0167	.1339
.0083	.1375
0	.1406
-.0083	.1431
-.0167	.1453
-.0250	.1472
-.0333	.1492
-.0417	.1508
-.0500	.1523
-.0583	.1536
-.0667	.1546
-.0750	.1554
-.0833	.1559
-.1340	0

x/l = 0.458

z/l	y/l
0.0800	0
.0799	.0083
.0797	.0167
.0794	.0250
.0788	.0333
.0780	.0417
.0768	.0500
.0755	.0583
.0739	.0667
.0720	.0750
.0694	.0833
.0664	.0917
.0629	.1000
.0581	.1083
.0526	.1167
.0453	.1250
.0363	.1333
.0292	.1379
.0250	.1407
.0167	.1454
.0083	.1491
0	.1521
-.0083	.1549
-.0167	.1571
-.0250	.1592
-.0333	.1611
-.0417	.1627
-.0500	.1642
-.0583	.1654
-.0667	.1664
-.0750	.1672
-.0833	.1677
-.1322	0

x/l = 0.500

z/l	y/l
0.0782	0
.0782	.0167
.0780	.0250
.0776	.0333
.0770	.0417
.0762	.0500
.0751	.0583
.0738	.0667
.0723	.0750
.0705	.0833
.0682	.0917
.0655	.1000
.0620	.1083
.0579	.1167
.0529	.1250
.0467	.1333
.0390	.1417
.0333	.1458
.0250	.1521
.0167	.1571
.0083	.1612
0	.1643
-.0083	.1672
-.0167	.1694
-.0250	.1715
-.0333	.1733
-.0417	.1750
-.0500	.1763
-.0583	.1775
-.0667	.1785
-.0750	.1792
-.1285	0

x/l = 0.542

z/l	y/l
0.0759	0
.0759	.0166
.0758	.0249
.0756	.0332
.0752	.0415
.0747	.0498
.0740	.0581
.0730	.0664
.0718	.0747
.0705	.0830
.0688	.0913
.0666	.0996
.0642	.1079
.0611	.1162
.0575	.1245
.0530	.1328
.0476	.1411
.0410	.1494
.0326	.1577
.0249	.1629
.0166	.1685
.0083	.1729
0	.1764
-.0083	.1790
-.0166	.1815
-.0249	.1834
-.0332	.1853
-.0415	.1869
-.0498	.1882
-.0581	.1893
-.0664	.1902
-.1229	0

x/l = 0.583

z/l	y/l
0.0741	0
.0741	.0104
.0740	.0271
.0735	.0437
.0726	.0604
.0710	.0771
.0671	.0937
.0668	.1020
.0651	.1104
.0626	.1187
.0596	.1270
.0563	.1354
.0521	.1437
.0471	.1520
.0412	.1604
.0337	.1687
.0250	.1756
.0167	.1813
.0083	.1860
0	.1897
-.0083	.1926
-.0167	.1949
-.0250	.1970
-.0333	.1988
-.0417	.2003
-.0500	.2017
-.0583	.2028
-.1156	0

x/l = 0.625

z/l	y/l
0.0716	0
.0716	.0104
.0716	.0271
.0713	.0437
.0707	.0604
.0696	.0771
.0678	.0937
.0655	.1104
.0637	.1187
.0616	.1270
.0591	.1354
.0558	.1437
.0521	.1520
.0478	.1604
.0429	.1687
.0365	.1770
.0292	.1842
.0250	.1878
.0167	.1941
.0083	.1991
0	.2028
-.0083	.2057
-.0167	.2080
-.0250	.2101
-.0333	.2118
-.0417	.2132
-.0500	.2143
-.1073	0

x/l = 0.667

z/l	y/l
0.0687	0
.0686	.0208
.0686	.0375
.0684	.0541
.0678	.0708
.0669	.0875
.0655	.1041
.0634	.1208
.0601	.1374
.0580	.1458
0.0555	0.1541
.0522	.1624
.0483	.1708
.0439	.1791
.0385	.1874
.0317	.1958
.0250	.2015
.0167	.2080
.0083	.2128
0	.2167
-.0083	.2197
-.0167	.2218
-.0250	.2237
-.0333	.2254
-.0417	.2264
-.0986	0

x/l = 0.708

z/l	y/l
0.0654	0
.0653	.0417
.0651	.0583
.0650	.0750
.0643	.0916
.0634	.1083
.0617	.1250
.0596	.1416
.0582	.1499
.0563	.1583
.0542	.1666
.0517	.1749
.0487	.1833
.0446	.1916
.0398	.1999
.0340	.2083
.0292	.2130
.0250	.2168
.0167	.2235
.0083	.2283
0	.2317
-.0083	.2343
-.0167	.2363
-.0250	.2378
-.0333	.2390
-.0889	0

x/l = 0.750

z/l	y/l
0.0617	0
.0616	.0625
.0615	.0791
.0611	.0958
.0606	.1125
.0596	.1291
.0581	.1458
.0561	.1624
.0533	.1791
.0488	.1958
.0458	.2041
.0421	.2124
.0372	.2207
.0333	.2256
.0292	.2307
.0250	.2347
.0167	.2409
.0083	.2447
0	.2470
-.0083	.2491
-.0167	.2504
-.0250	.2511
-.0785	0

x/l = 0.792

z/l	y/l
0.0578	0
.0577	.0937
.0576	.1104
.0573	.1270
.0569	.1437
.0561	.1604
.0549	.1770
.0532	.1937
.0506	.2103
.0486	.2187
.0460	.2270
.0425	.2353
.0375	.2437
.0333	.2481
.0250	.2551
.0167	.2588
.0083	.2611
0	.2624
-.0083	.2631
-.0167	.2634
-.0673	0

x/l = 0.833

z/l	y/l
0.0536	0
.0534	.1666
.0532	.1833
.0528	.1999
.0521	.2166
.0510	.2332
.0482	.2499
.0455	.2582
.0400	.2666
.0333	.2707
.0250	.2736
.0167	.2749
.0083	.2753
0	.2753
0.0563	0

x/l = 0.875

z/l	y/l
0.0487	0
-.0452	0

x/l = 0.917

z/l	y/l
0.0440	0
-.0341	0

x/l = 0.958

z/l	y/l
0.0392	0
-.0227	0

x/l = 1.000

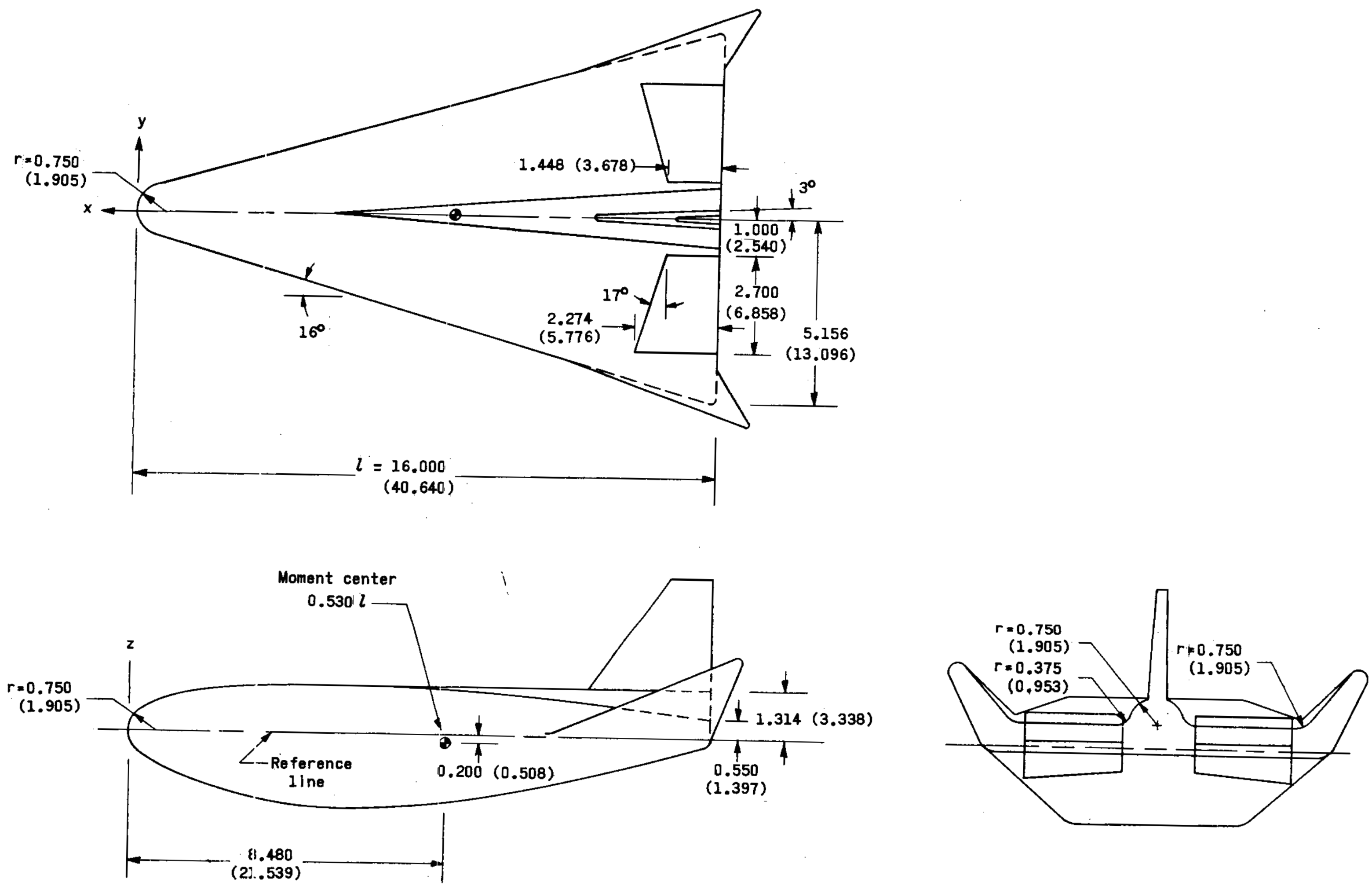
z/l	y/l
0.0344	0
-.0125	0

TABLE II.- HL-11 ORDINATES WITH TIP FINS OFF

z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l	z/l	y/l
x/l = 0.125		x/l = 0.250		x/l = 0.375		x/l = 0.500		x/l = 0.625		x/l = 0.750		x/l = 0.875	
0.081	0	0.100	0	0.107	0	0.103	0	0.089	0	0.071	0	0.071	0
.079	.016	.099	.016	.107	.016	.103	.016	.089	.031	.070	.016	.068	.016
.073	.044	.097	.031	.106	.031	.103	.031	.089	.063	.070	.031	.058	.031
.063	.045	.092	.047	.104	.047	.102	.047	.088	.094	.070	.063	.047	.047
.047	.056	.084	.063	.100	.063	.101	.063	.085	.125	.070	.125	.047	.063
.031	.062	.071	.078	.095	.078	.099	.078	.082	.141	.069	.172	.047	.125
.016	.066	.063	.084	.086	.094	.095	.094	.077	.156	.063	.205	.047	.188
0	.069	.047	.093	.073	.109	.090	.109	.069	.172	.047	.236	.047	.289
-.016	.070	.031	.099	.063	.118	.082	.125	.063	.180	.031	.247	.031	.289
-.031	.070	.016	.103	.047	.127	.071	.141	.047	.195	.016	.251	.016	.289
-.047	.069	0	.105	.031	.134	.063	.149	.031	.204	0	.252	0	.288
-.084	0	-.016	.106	.016	.138	.047	.160	.016	.210	-.016	.252	-.048	0
		-.031	.106	0	.140	.031	.168	0	.213	-.071	0		
		-.047	.106	-.016	.142	.016	.173	-.016	.215				
		-.063	.105	-.031	.142	0	.176	-.031	.215				
		-.078	.101	-.047	.143	-.016	.178	-.047	.214				
		-.102	0	-.063	.142	-.031	.179	-.063	.146				
				-.078	.140	-.047	.179	-.090	0				
				-.108	0	-.063	.177						
						-.078	.173						
						-.103	0						

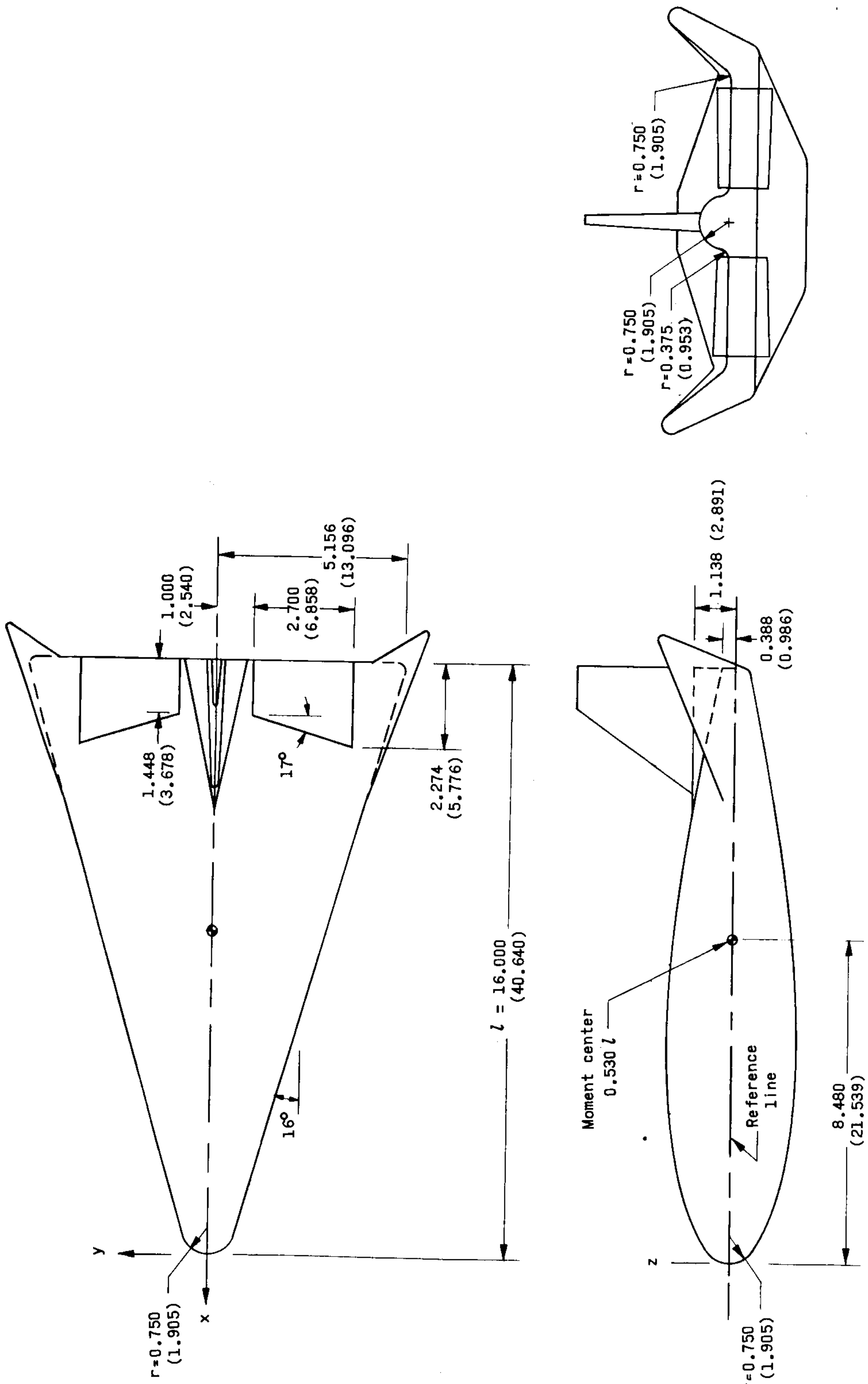
TABLE III.- TIP-FIN TOE-IN AND ROLL-OUT ANGLES

Fin	ϵ, deg			ϕ, deg		
	Left	Right	Average	Left	Right	Average
D-1			≈16	25.5	25.5	25.5
P_1, lower panel . . .			5.0			15.0
P_1, upper panel . . .			0			0
I_1	12.9	13.2	13.1	22.8	24.0	23.4
I_2	15.3	16.4	15.9	9.8	9.4	9.6
I_3	10.8	10.7	10.8	7.8	9.2	8.5
I_4	11.0	10.8	10.9	8.5	8.5	8.5



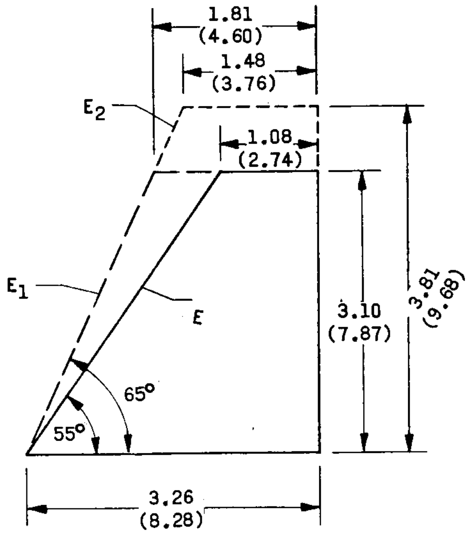
(a) HL-10.

Figure 1.- Model drawings. (All dimensions are in inches unless otherwise noted; parenthetical dimensions are in centimeters.)

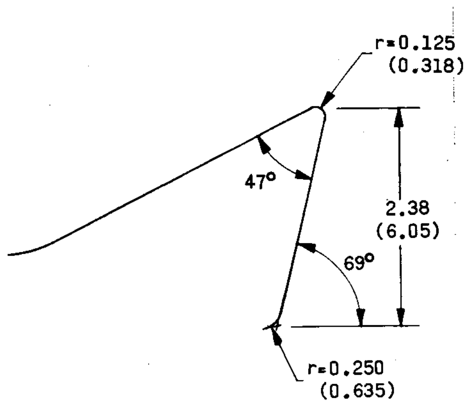


(b) HL-11.

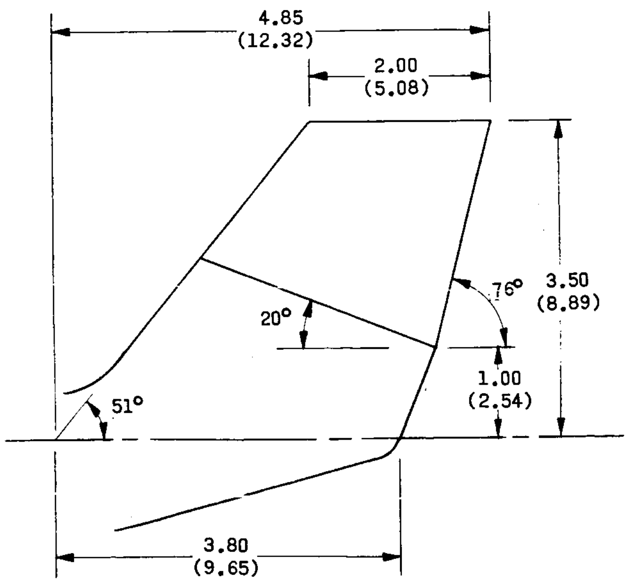
Figure 1.- Continued.



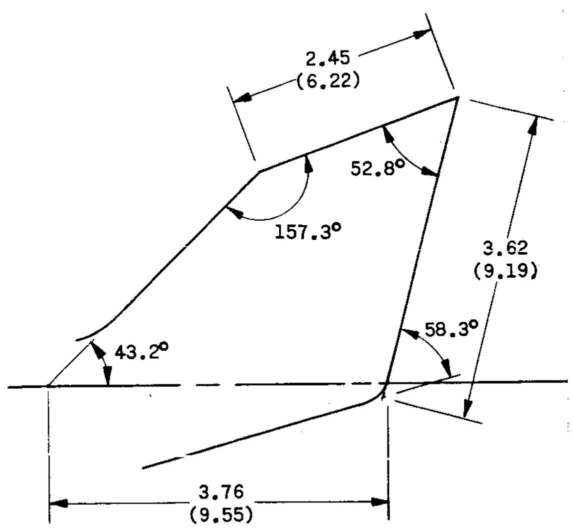
E-series center fins



D-1 tip fins



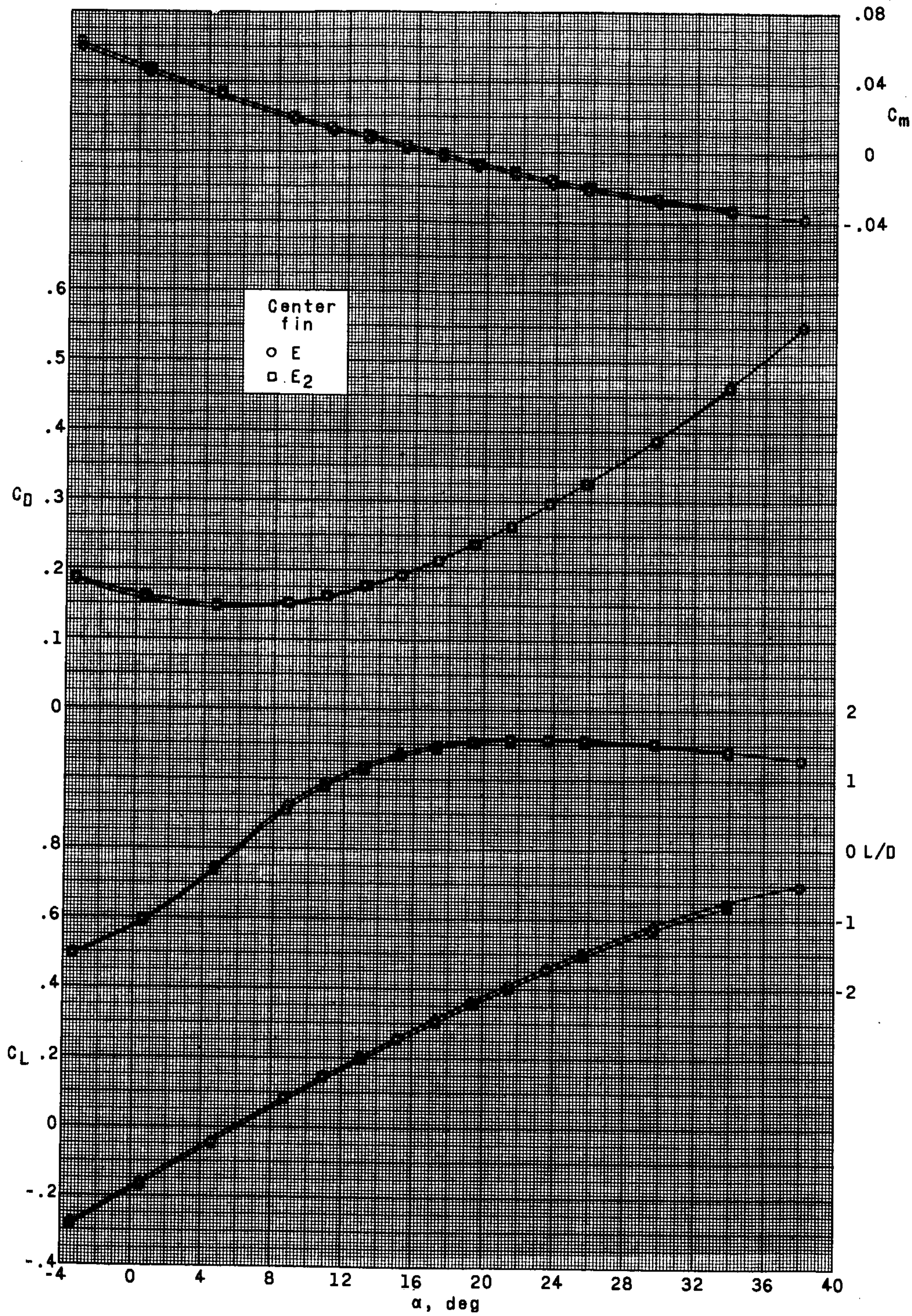
P_1 tip fins



I-series tip fins

(c) Fin geometry.

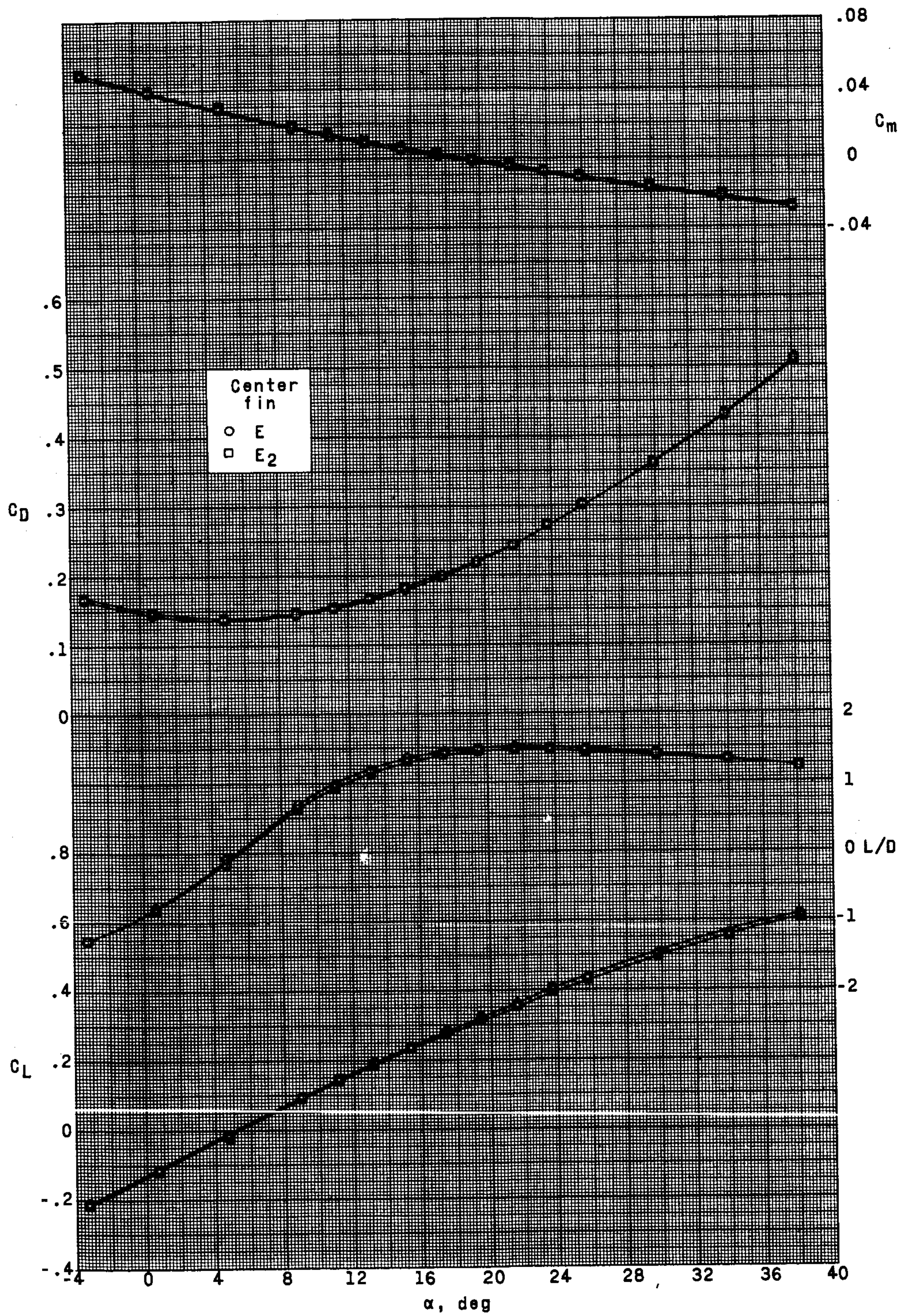
Figure 1.- Concluded.



(a) M = 1.50.

Figure 2.- Effects of center fins E and E_2 on longitudinal characteristics of HL-10 with tip fins P_1.

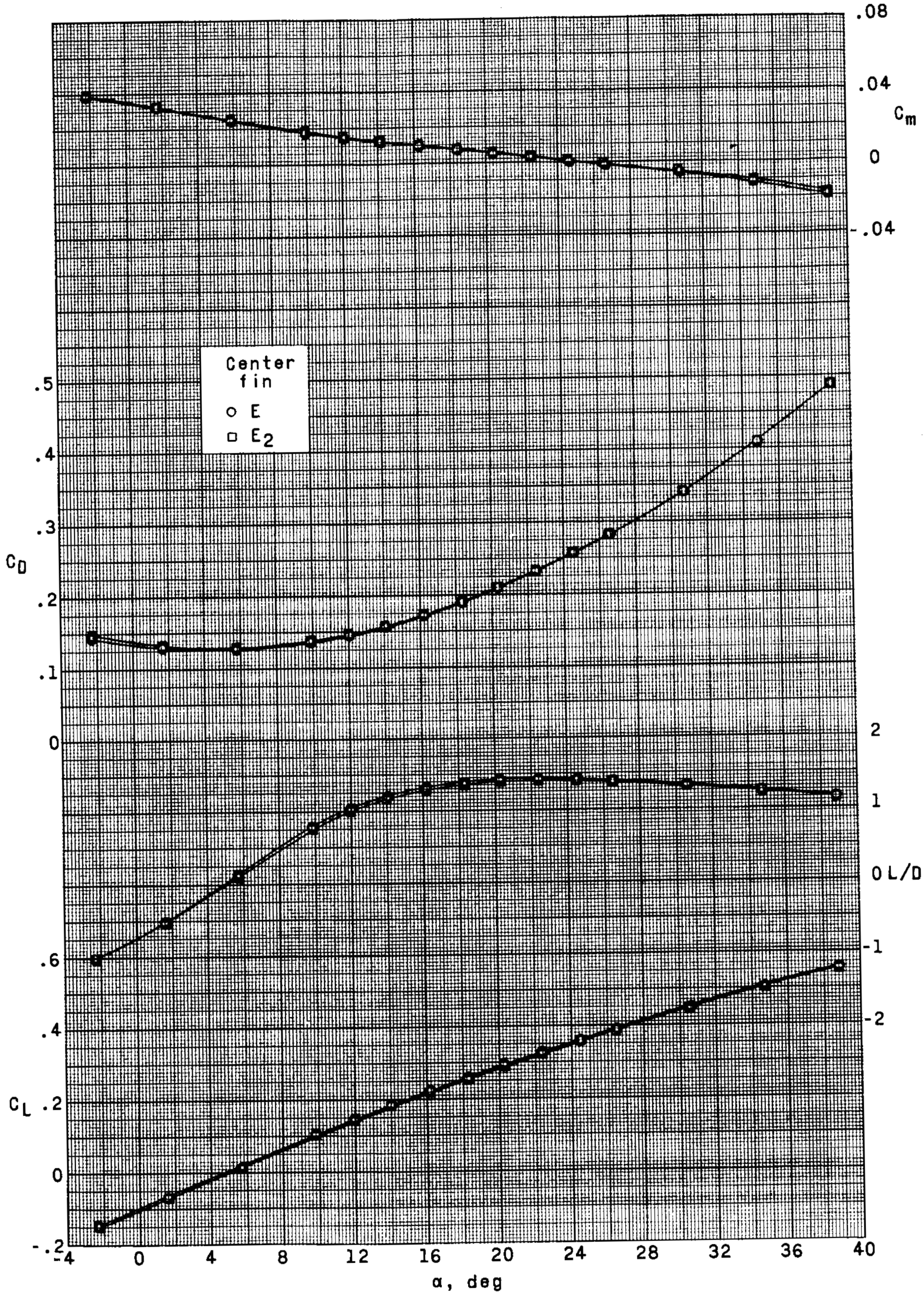
[redacted]



(b) M = 1.80.

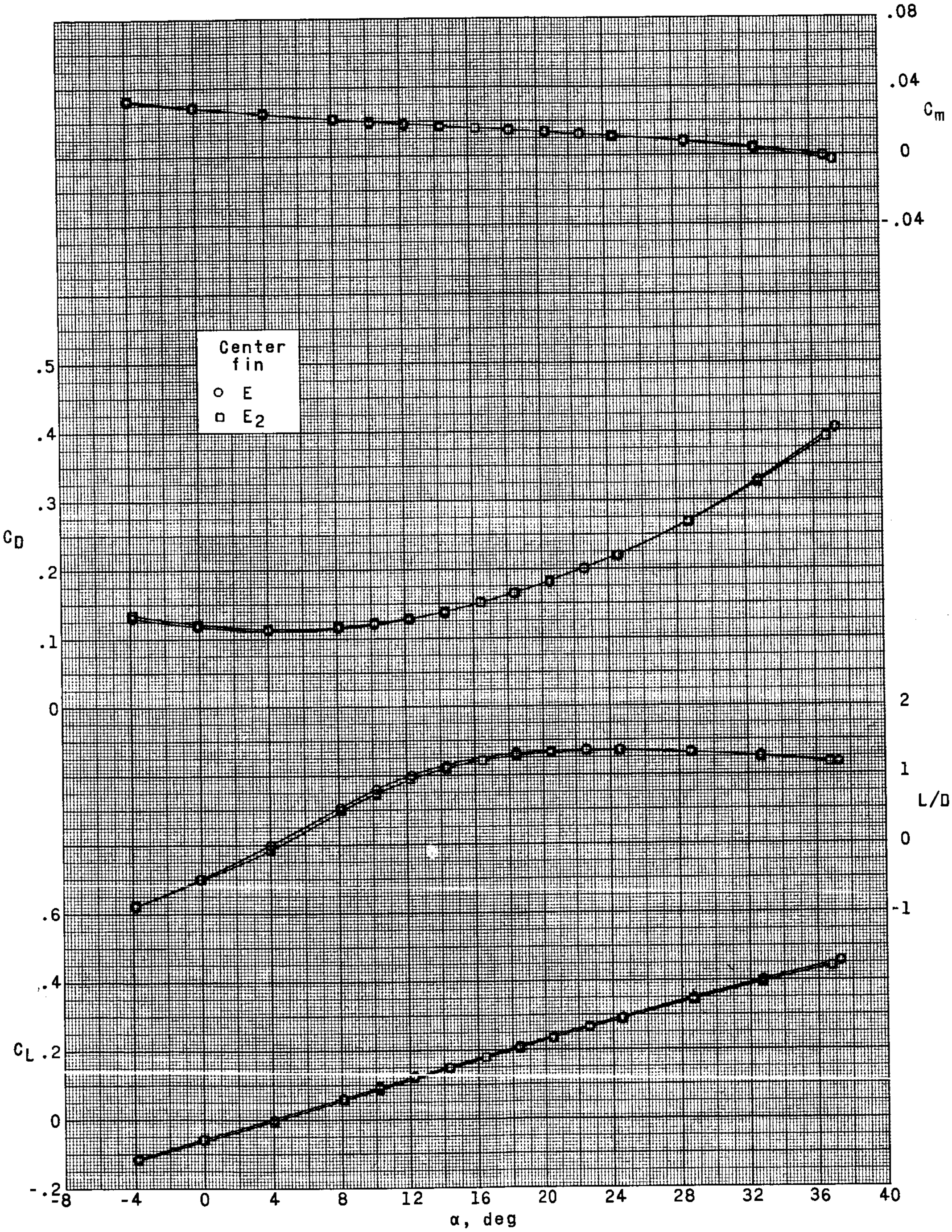
Figure 2.- Continued.

[redacted]



(c) M = 2.16.

Figure 2.- Continued.



(d) M = 2.86.

Figure 2.- Concluded.

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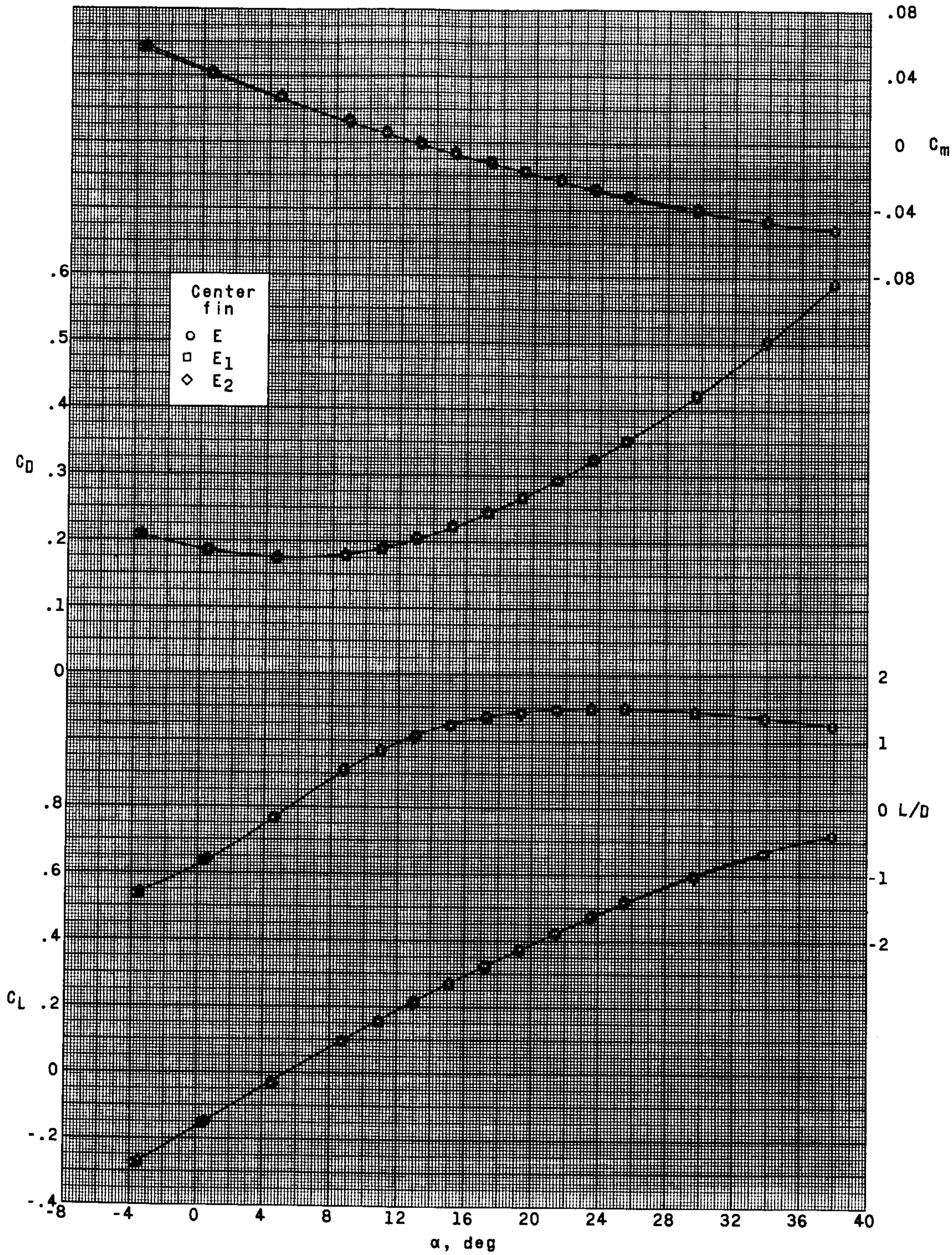
[redacted]

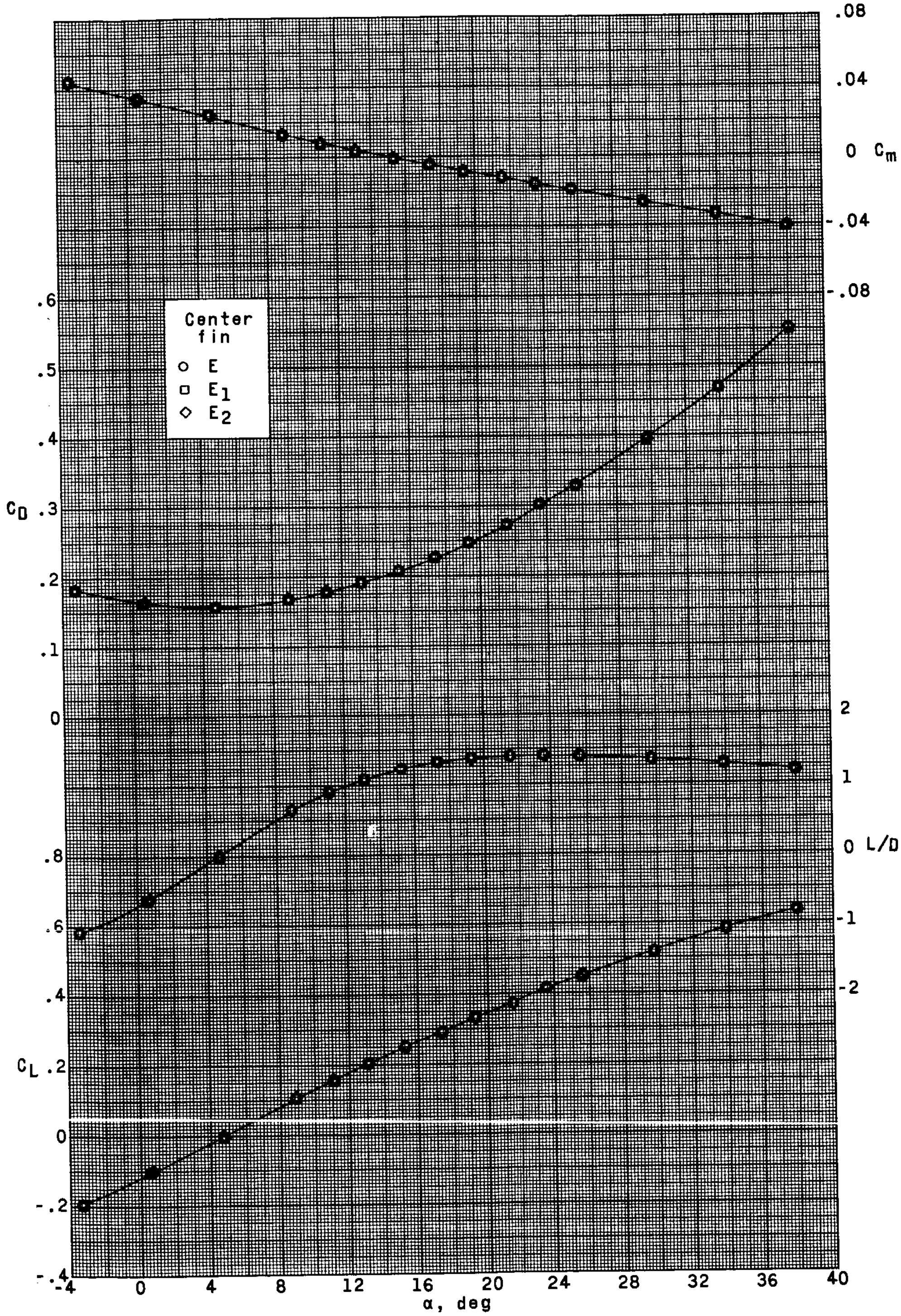


(a) M = 1.50.

Figure 3.- Effects of center fins E, E_1, and E_2 on longitudinal characteristics of HL-10 with tip fins I_2.

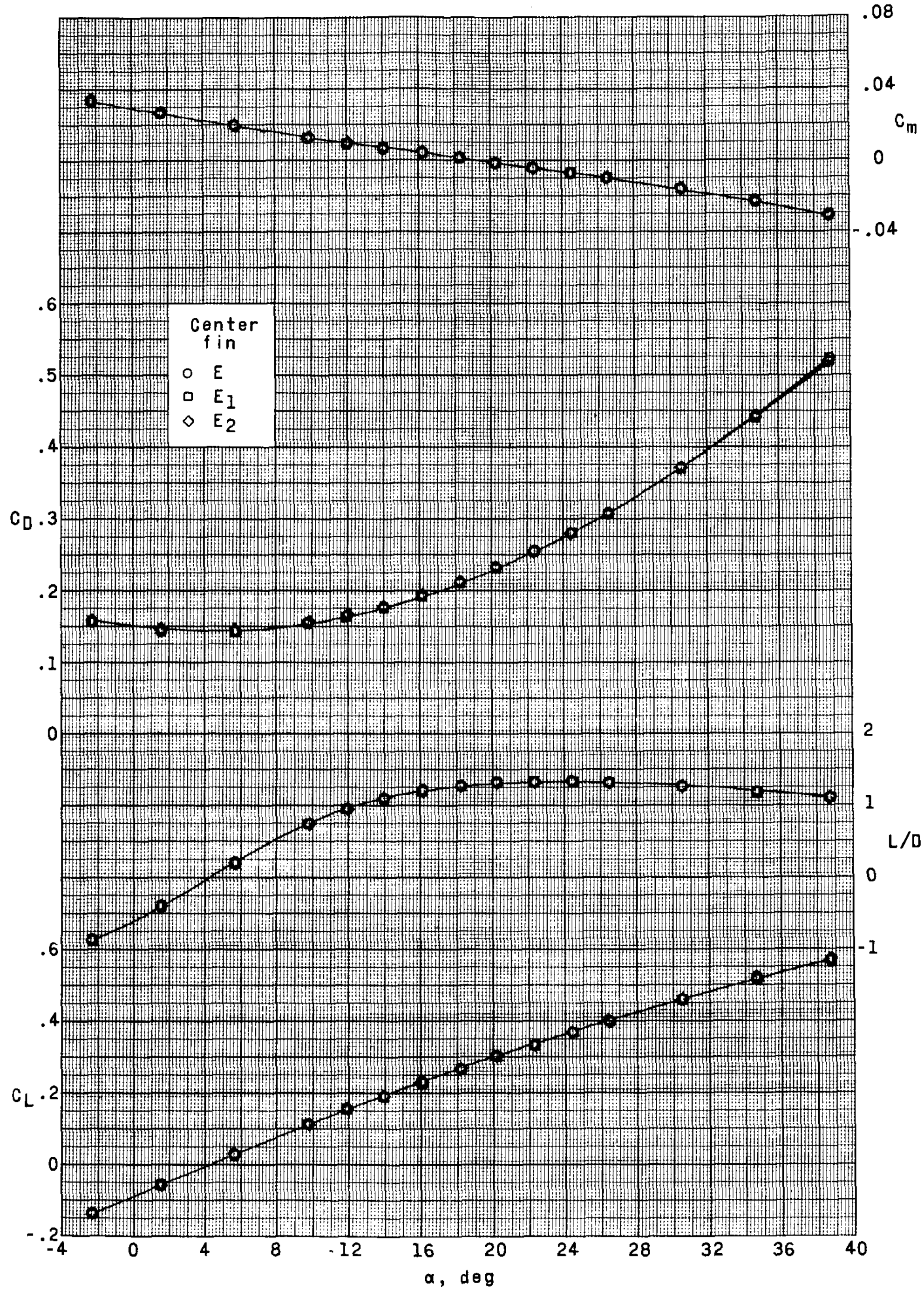
[redacted]

UNCLASSIFIED



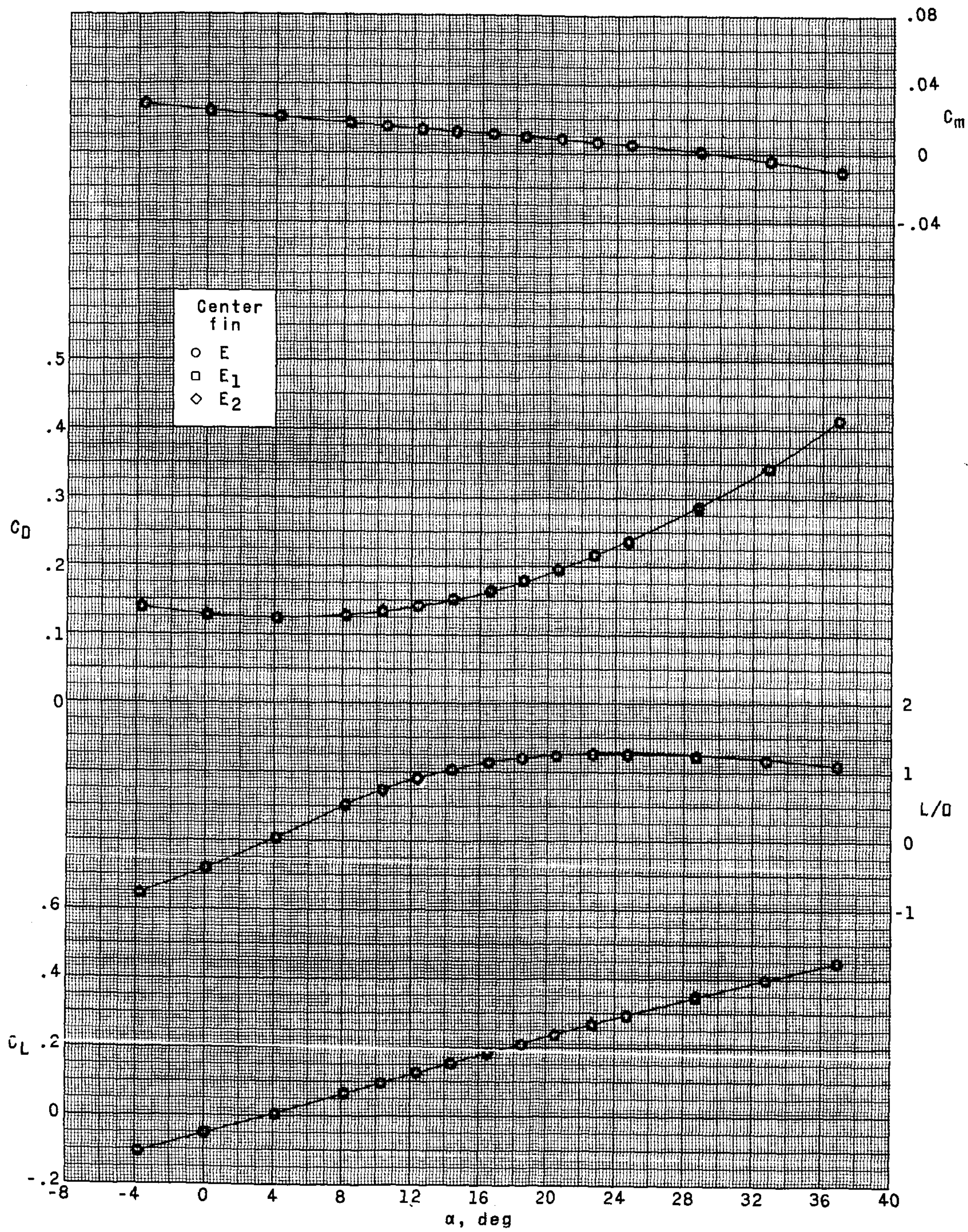
(b) M = 1.80.

Figure 3.- Continued.



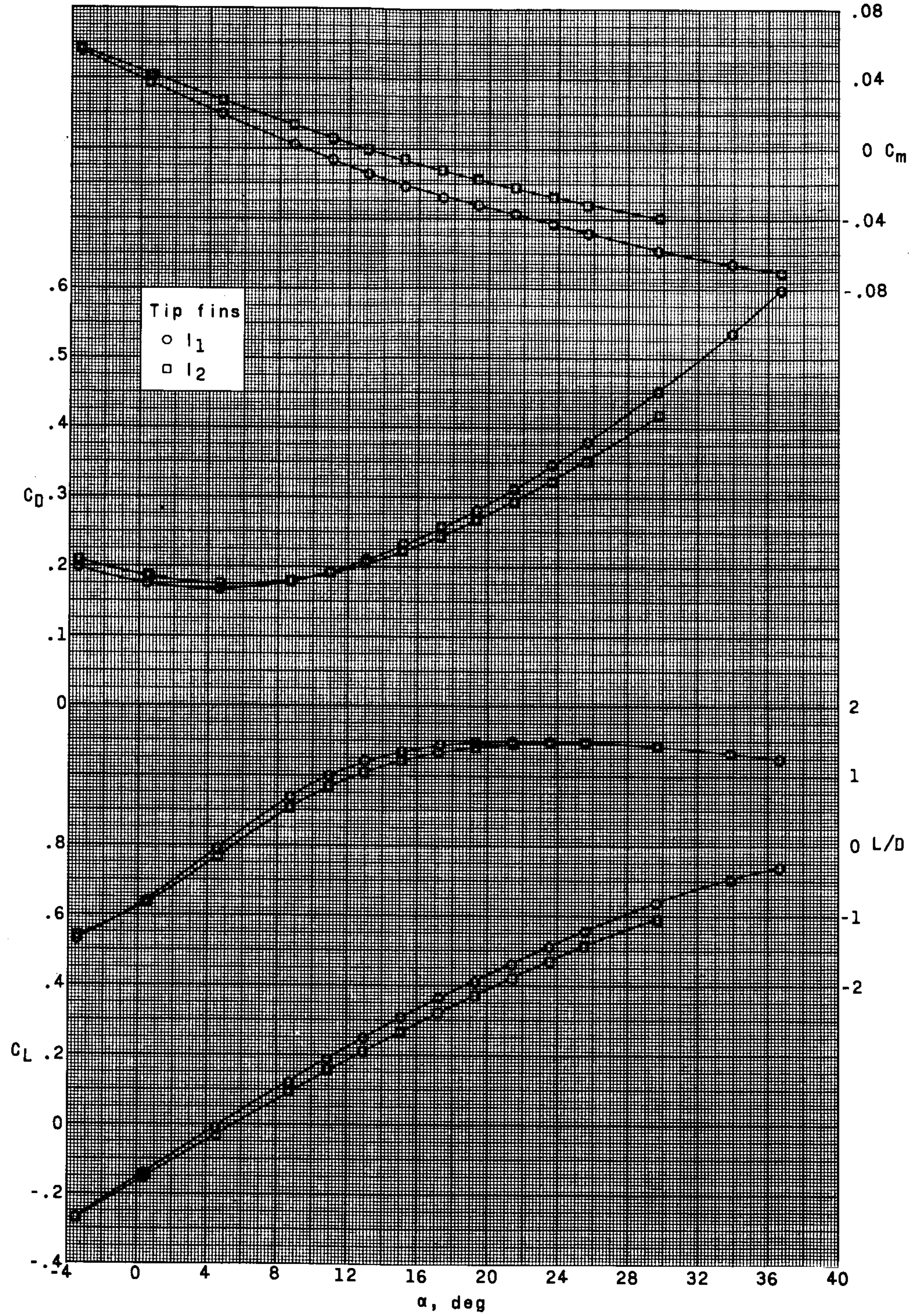
(c) M = 2.16.

Figure 3.- Continued.



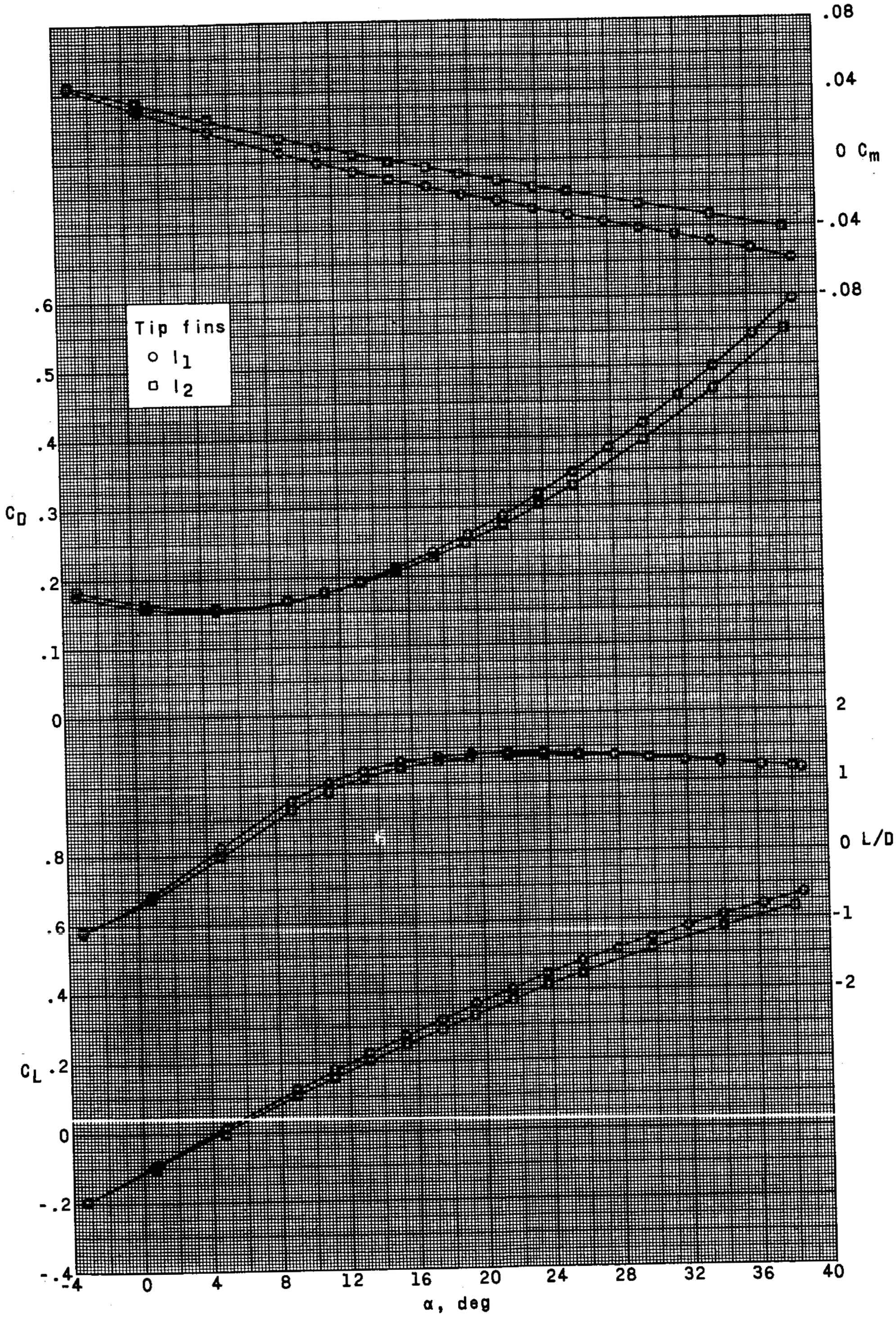
(d) M = 2.86.

Figure 3.- Concluded.



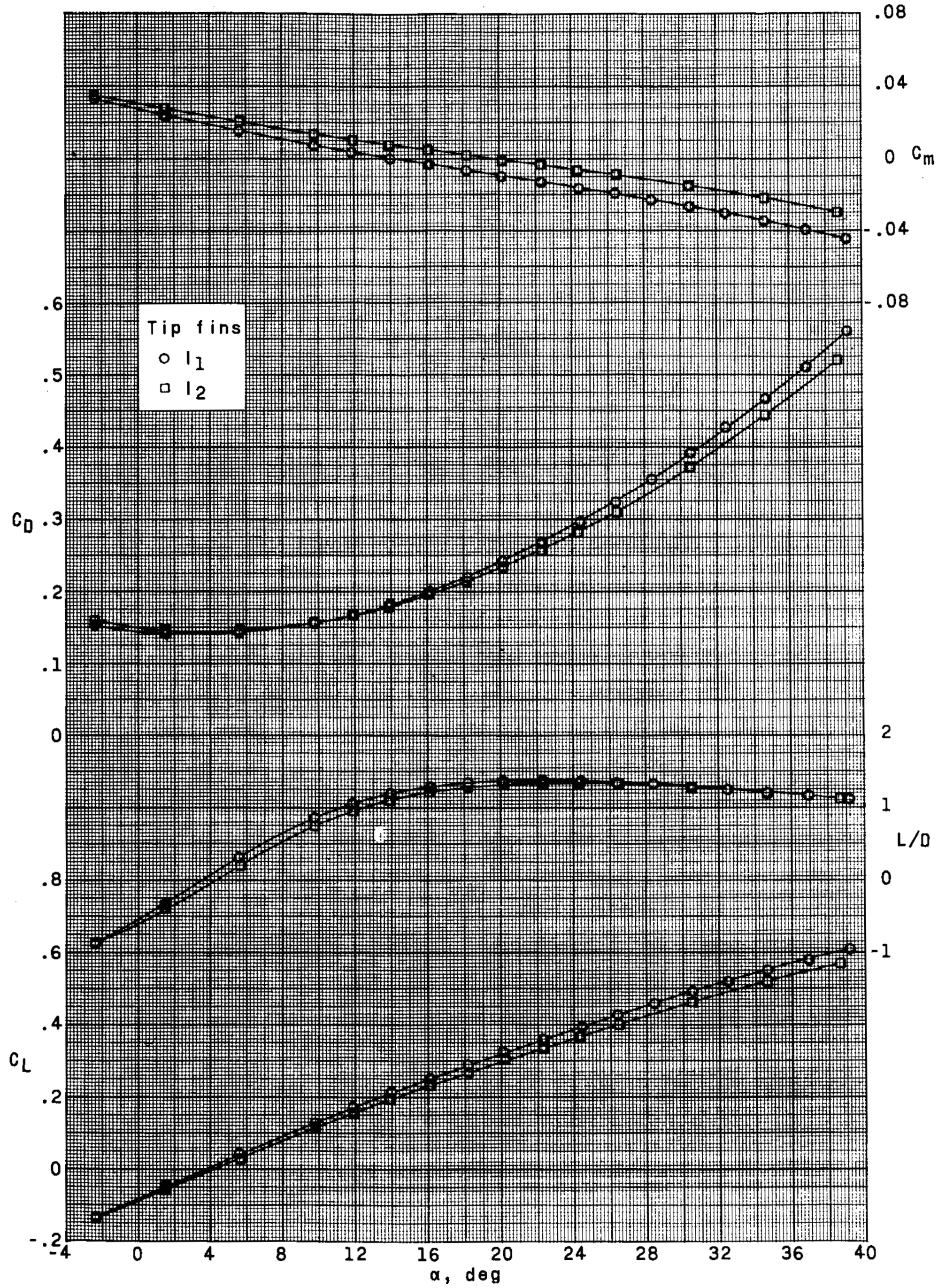
(a) M = 1.50.

Figure 4.- Effects of tip fins I_1 and I_2 on longitudinal characteristics of HL-10 with center fin E_2.



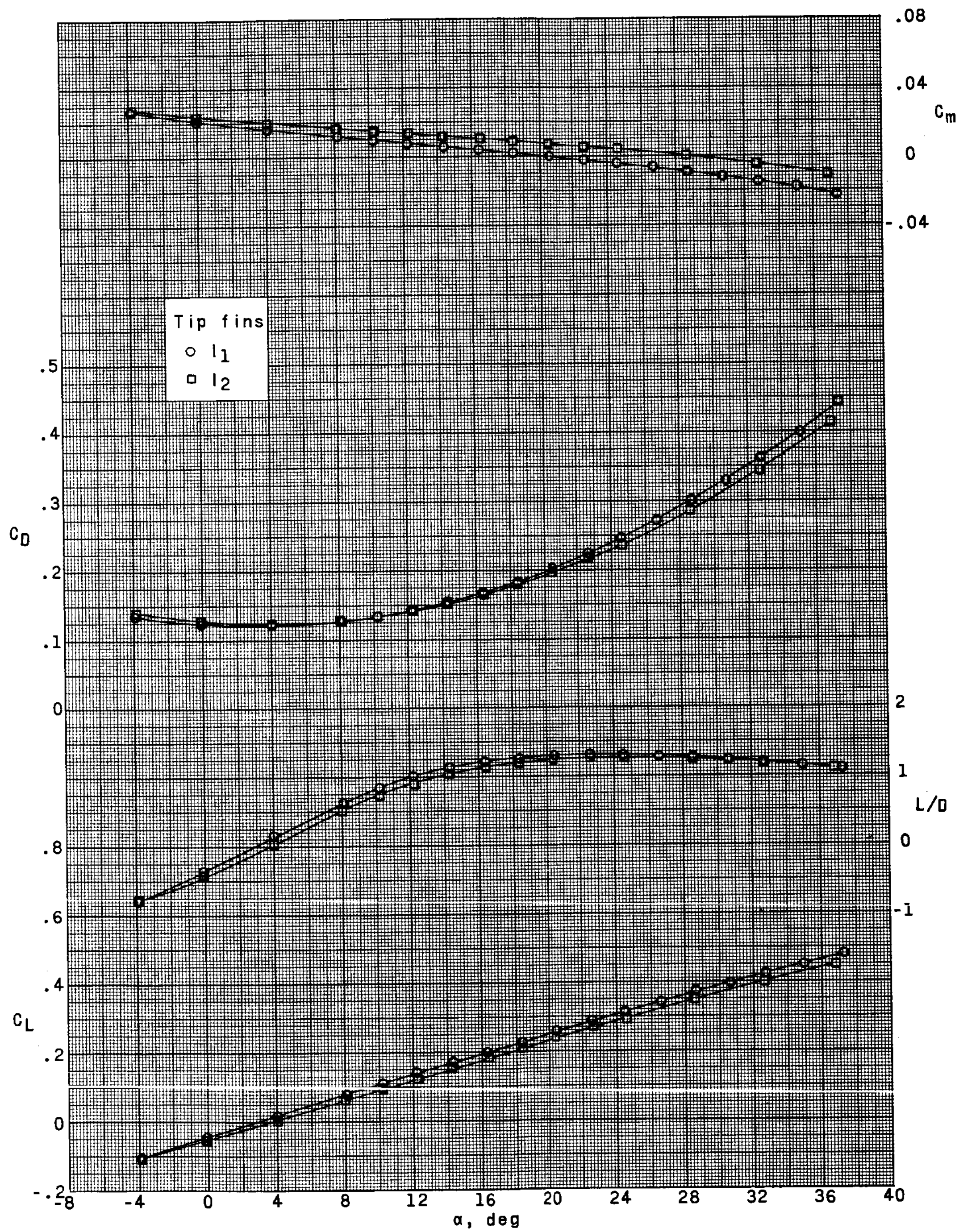
(b) M = 1.80.

Figure 4.- Continued.



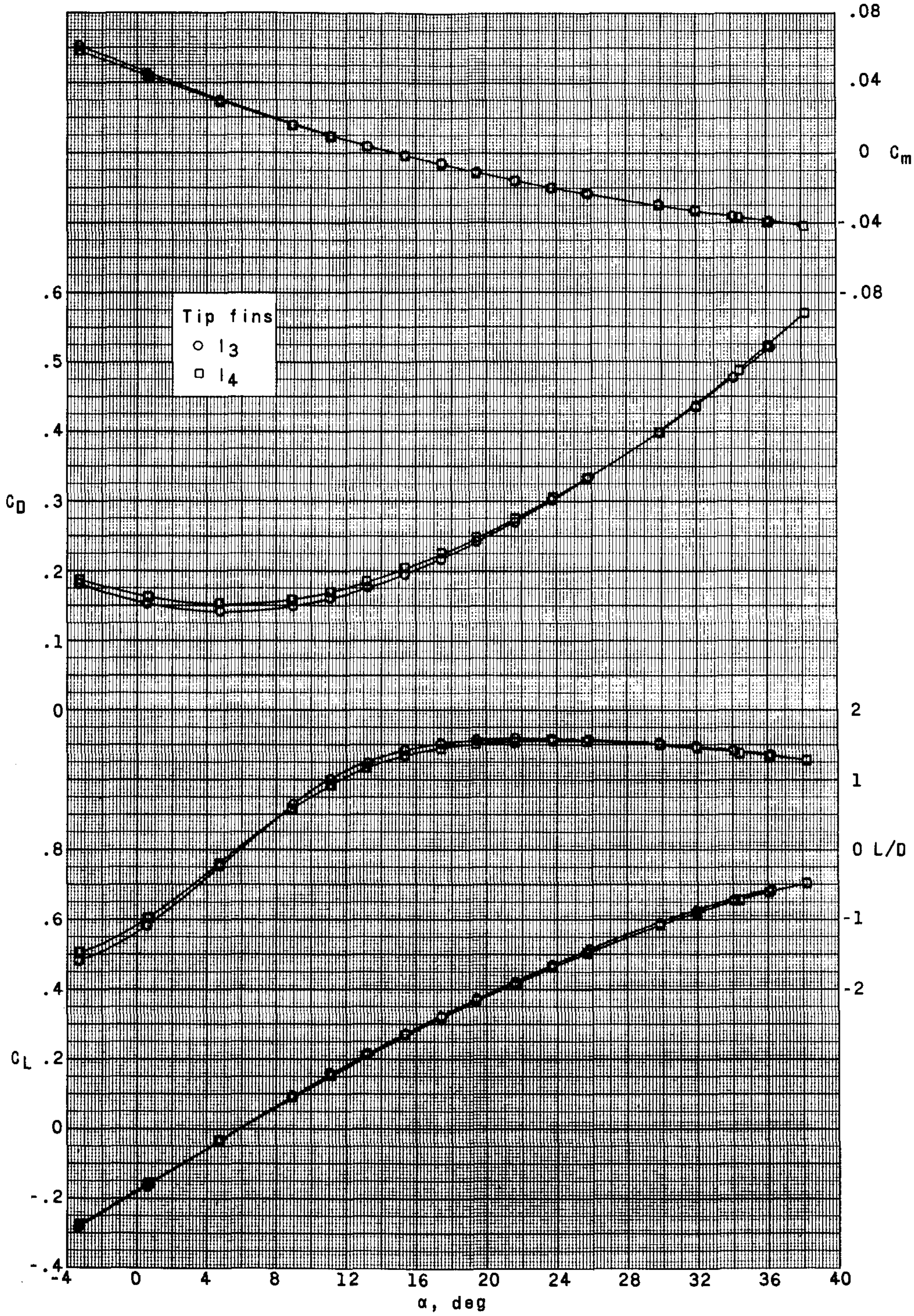
(c) M = 2.16.

Figure 4.- Continued.



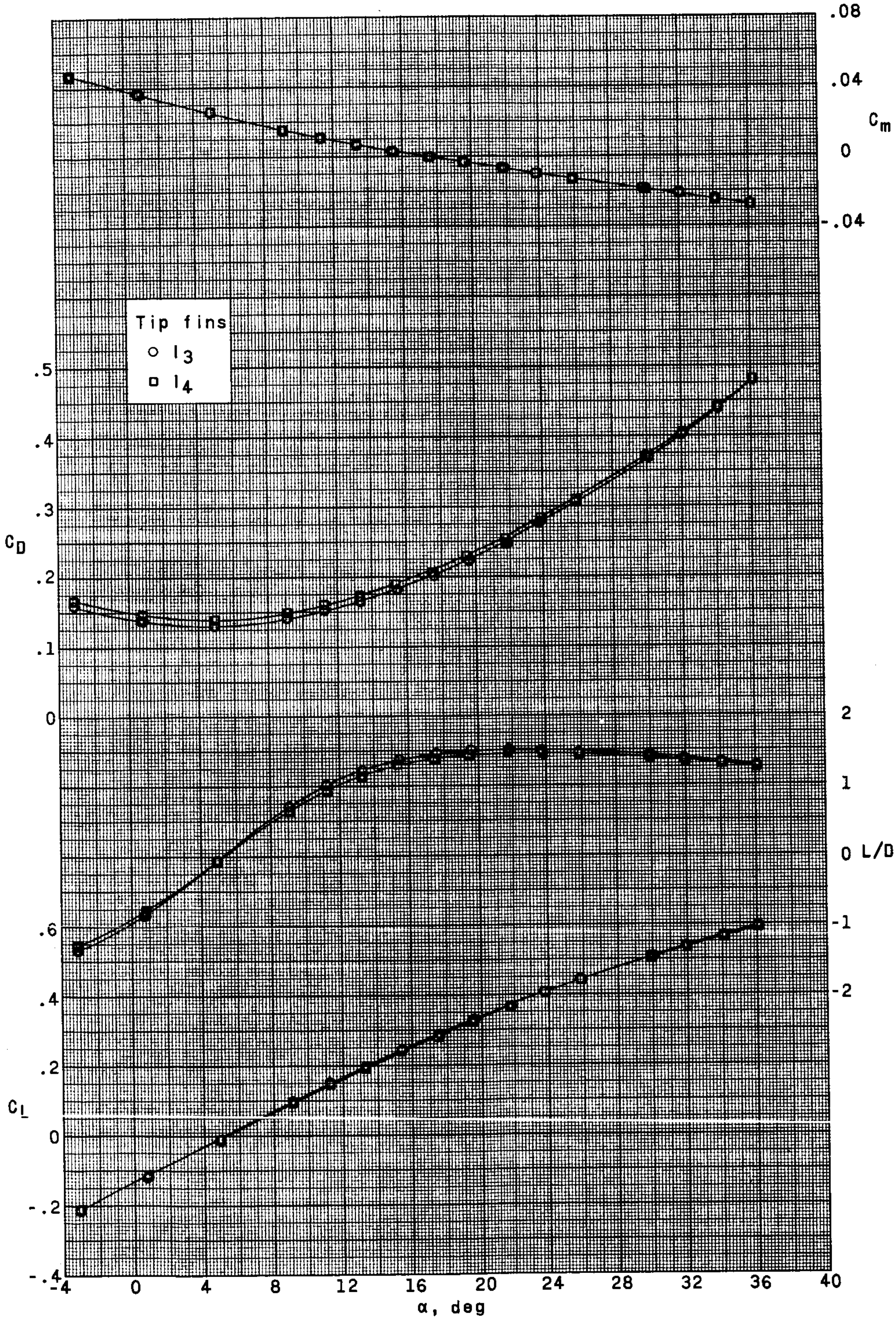
(d) M = 2.86.

Figure 4.- Concluded.



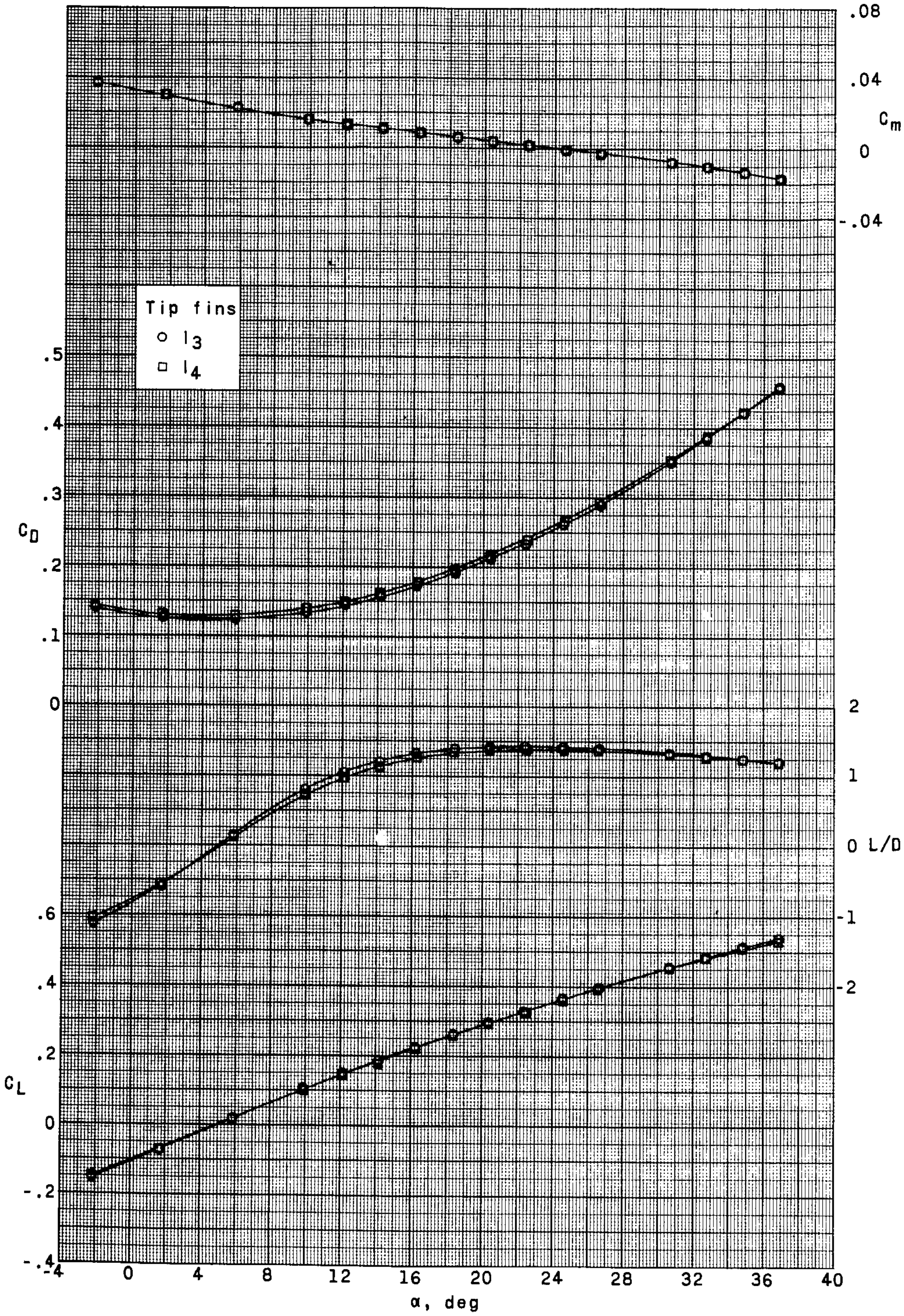
(a) $M = 1.50$.

Figure 5.- Effects of tip fins I_3 and I_4 on longitudinal characteristics of HL-10 with center fin E_2.



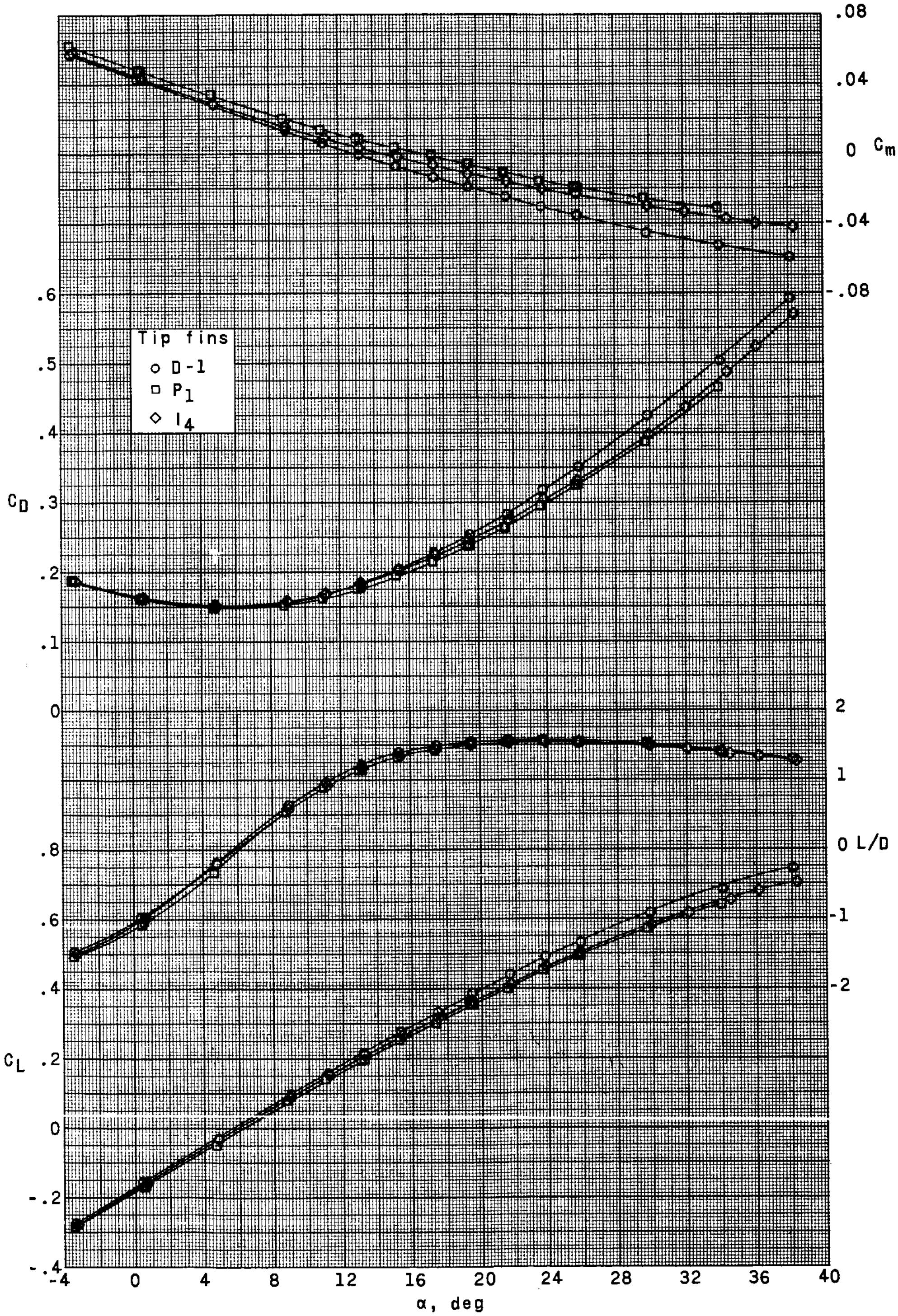
(b) M = 1.80.

Figure 5.- Continued.



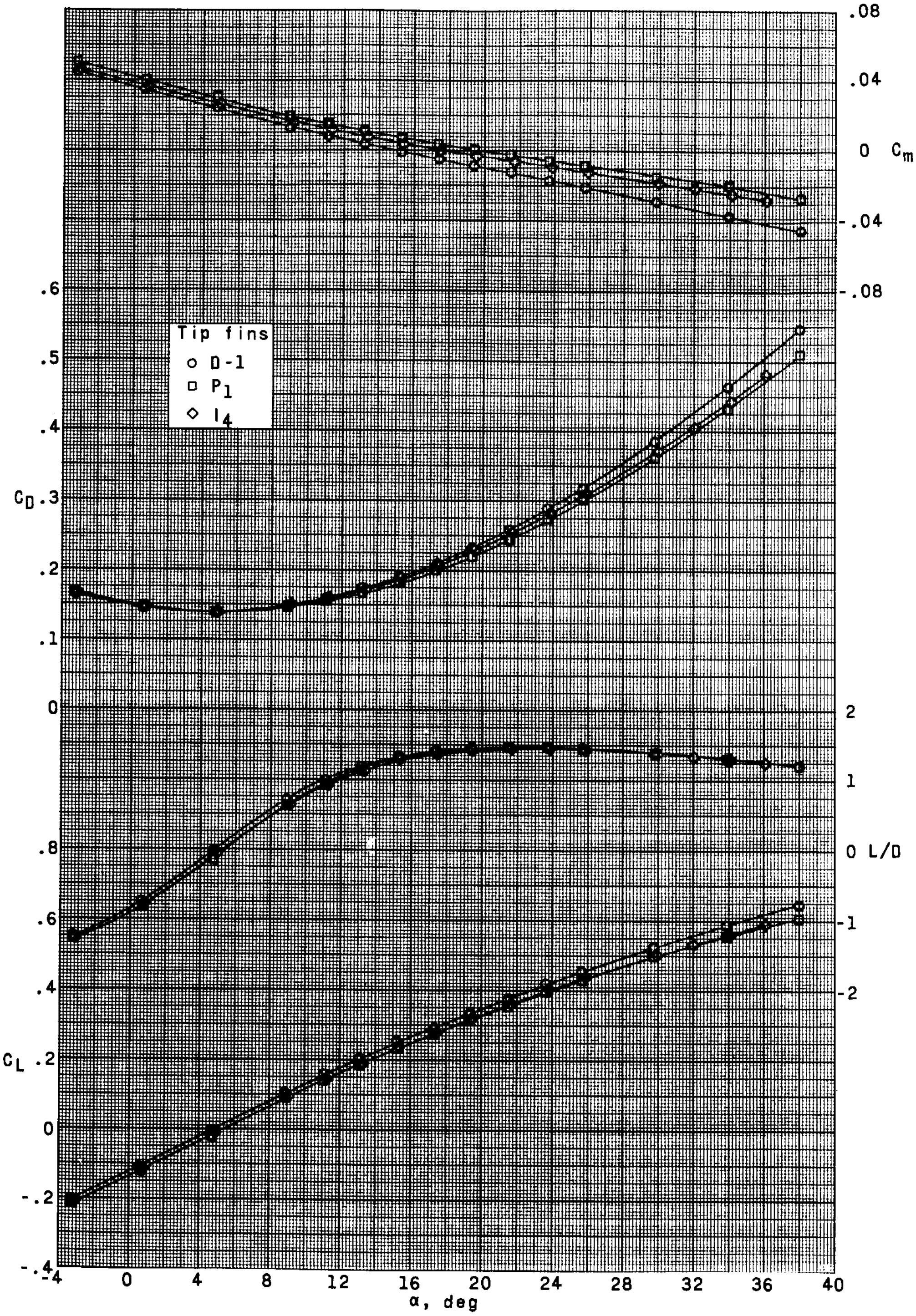
(c) M = 2.16.

Figure 5.- Concluded.



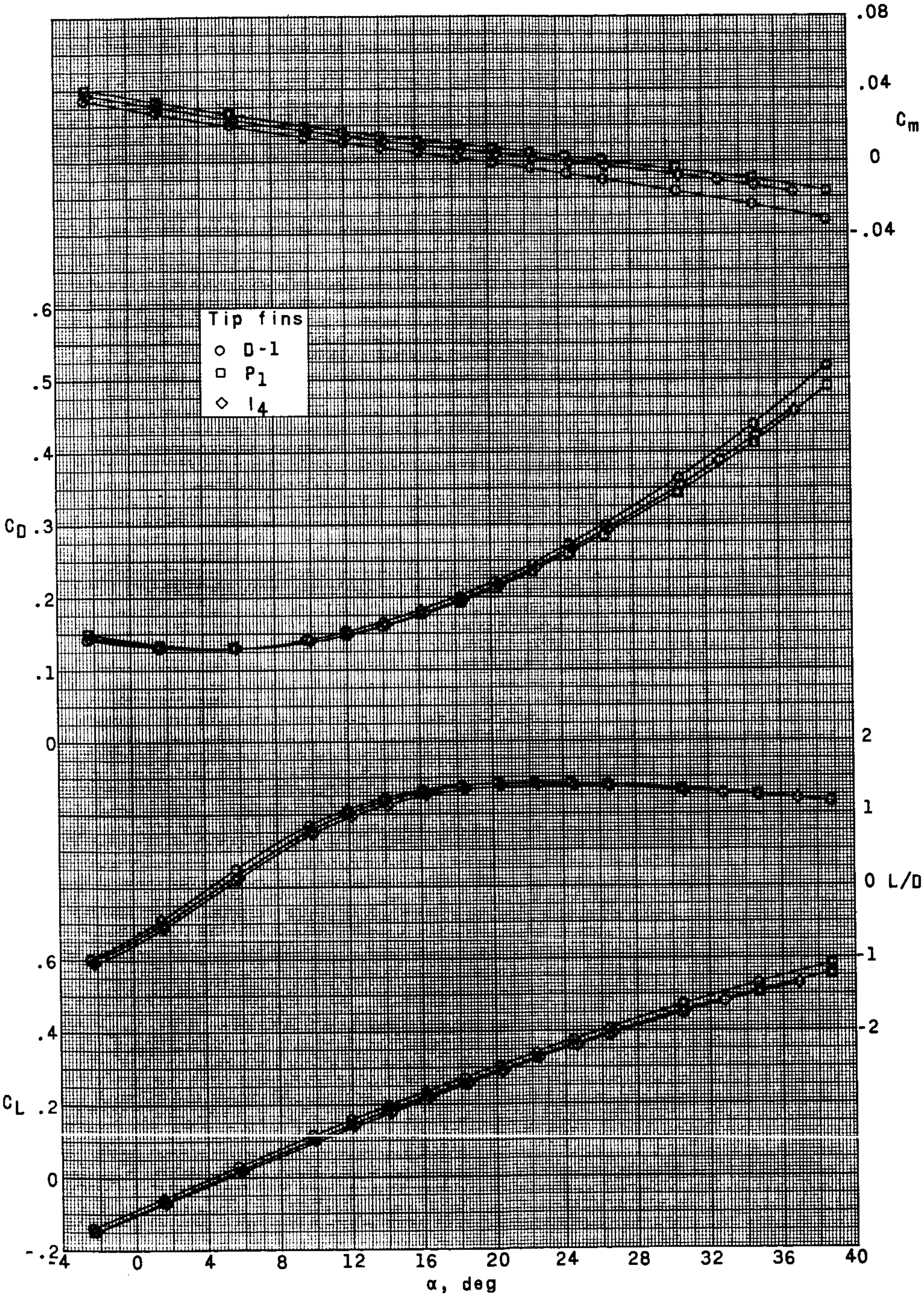
(a) M = 1.50.

Figure 6.- Effects of tip fins D-1, P_1, and I_4 on longitudinal characteristics of HL-10 with center fin E_2.



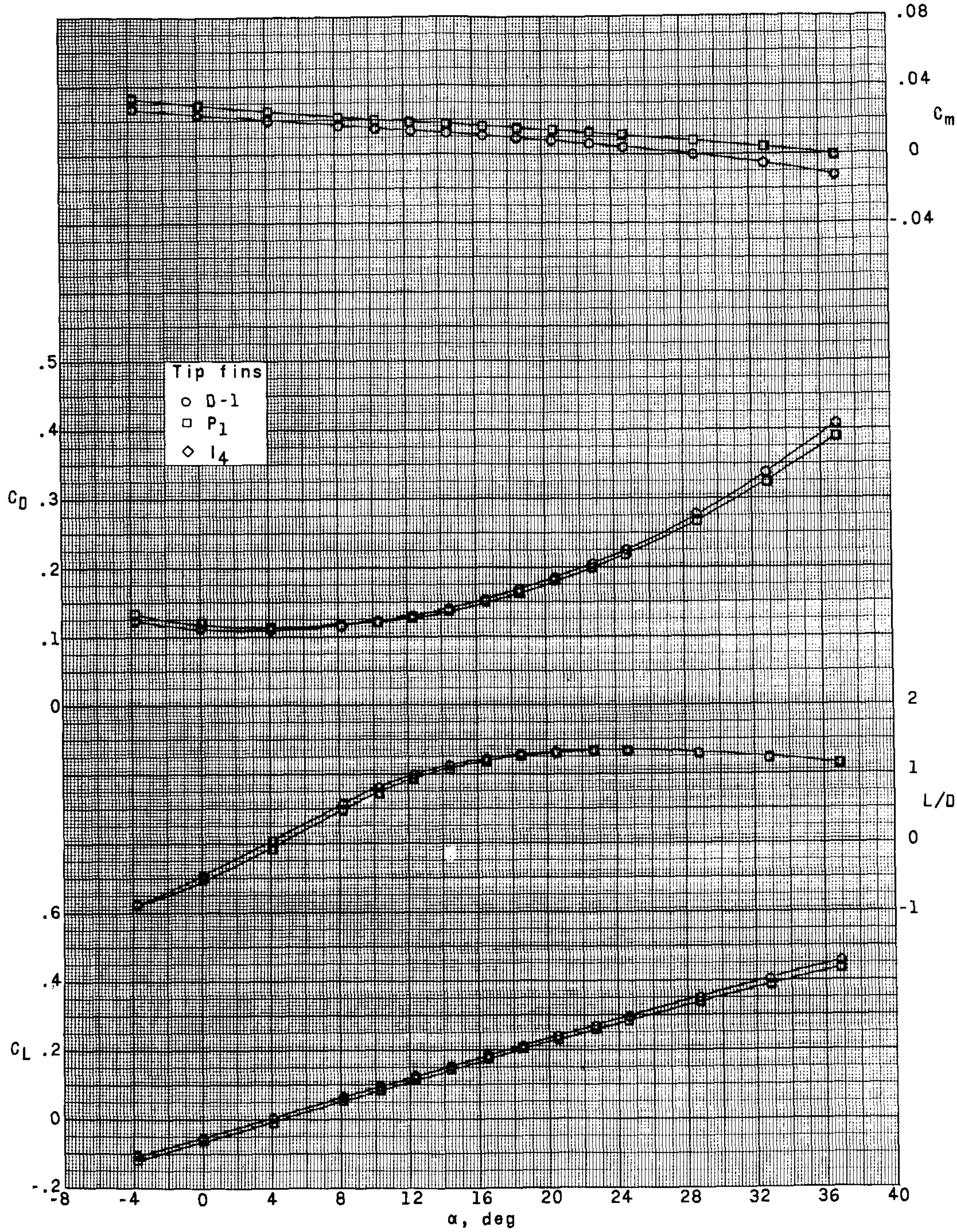
(b) M = 1.80.

Figure 6.- Continued.



(c) M = 2.16.

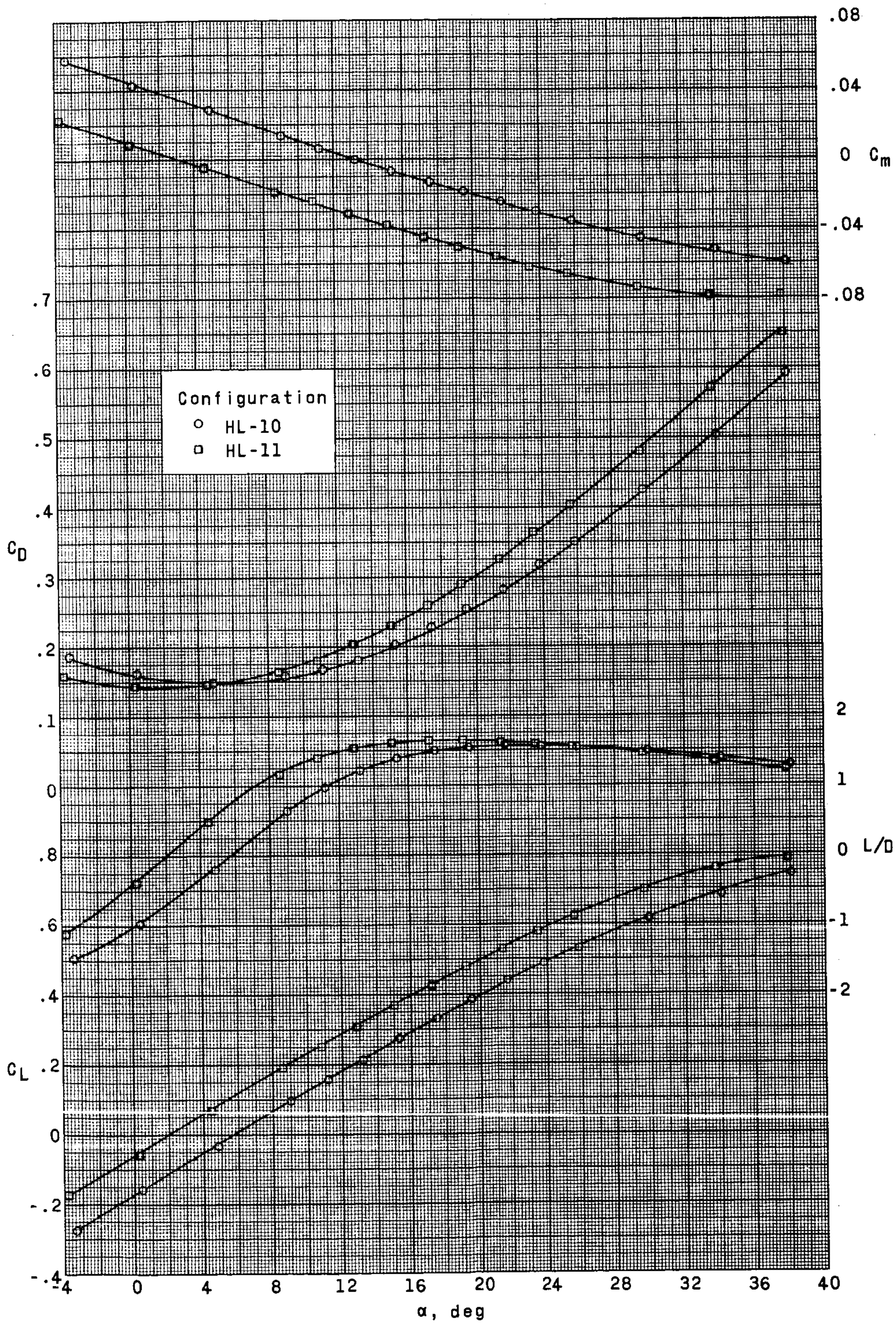
Figure 6.- Continued.



(d) M = 2.86.

Figure 6.- Concluded.

[redacted]



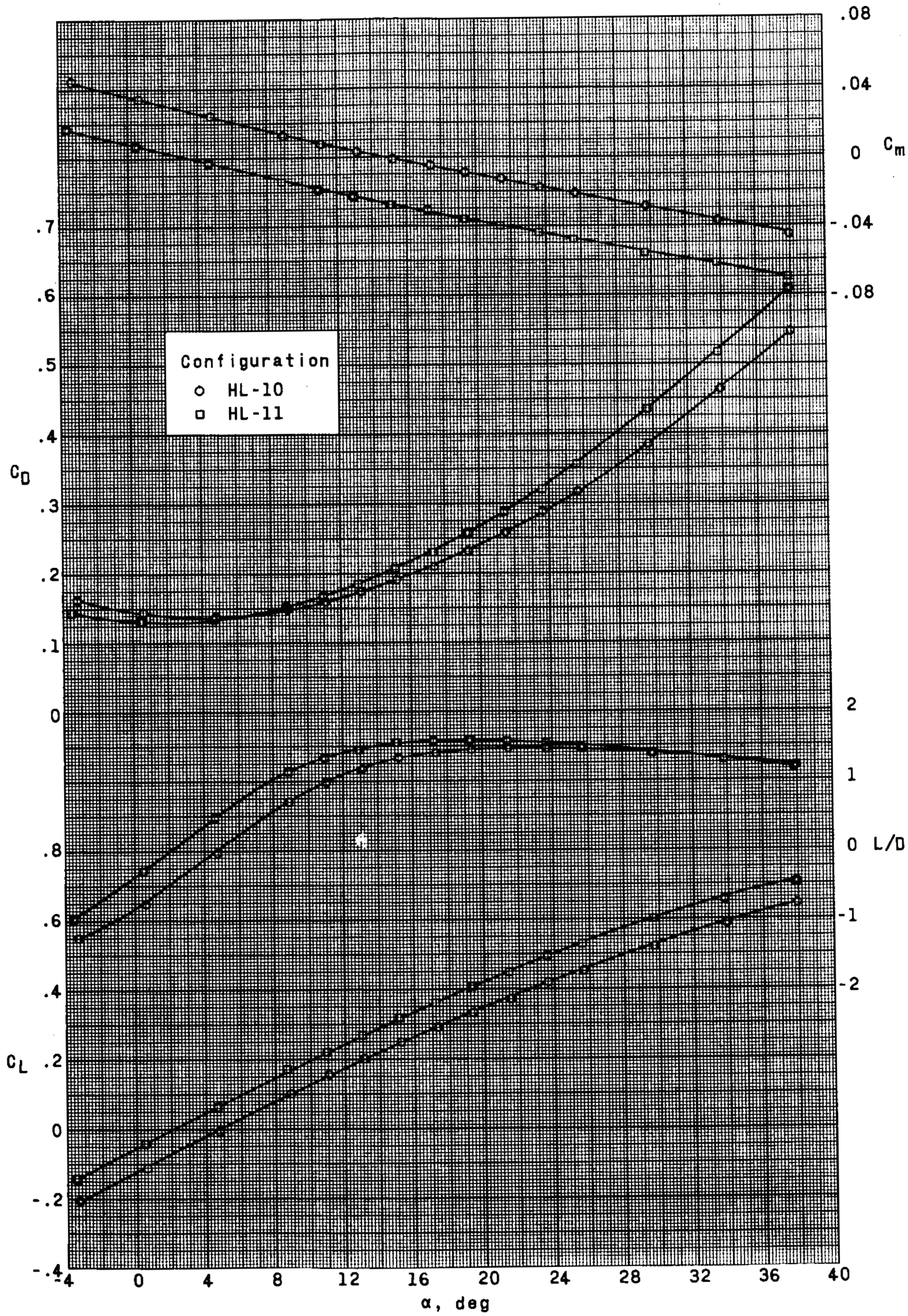
(a) M = 1.50.

Figure 7.- Effects of HL-10 (E_2 center fin) and HL-11 (E center fin) configurations with D-1 tip fins on longitudinal characteristics.

[redacted]

UNCLASSIFIED

[redacted]

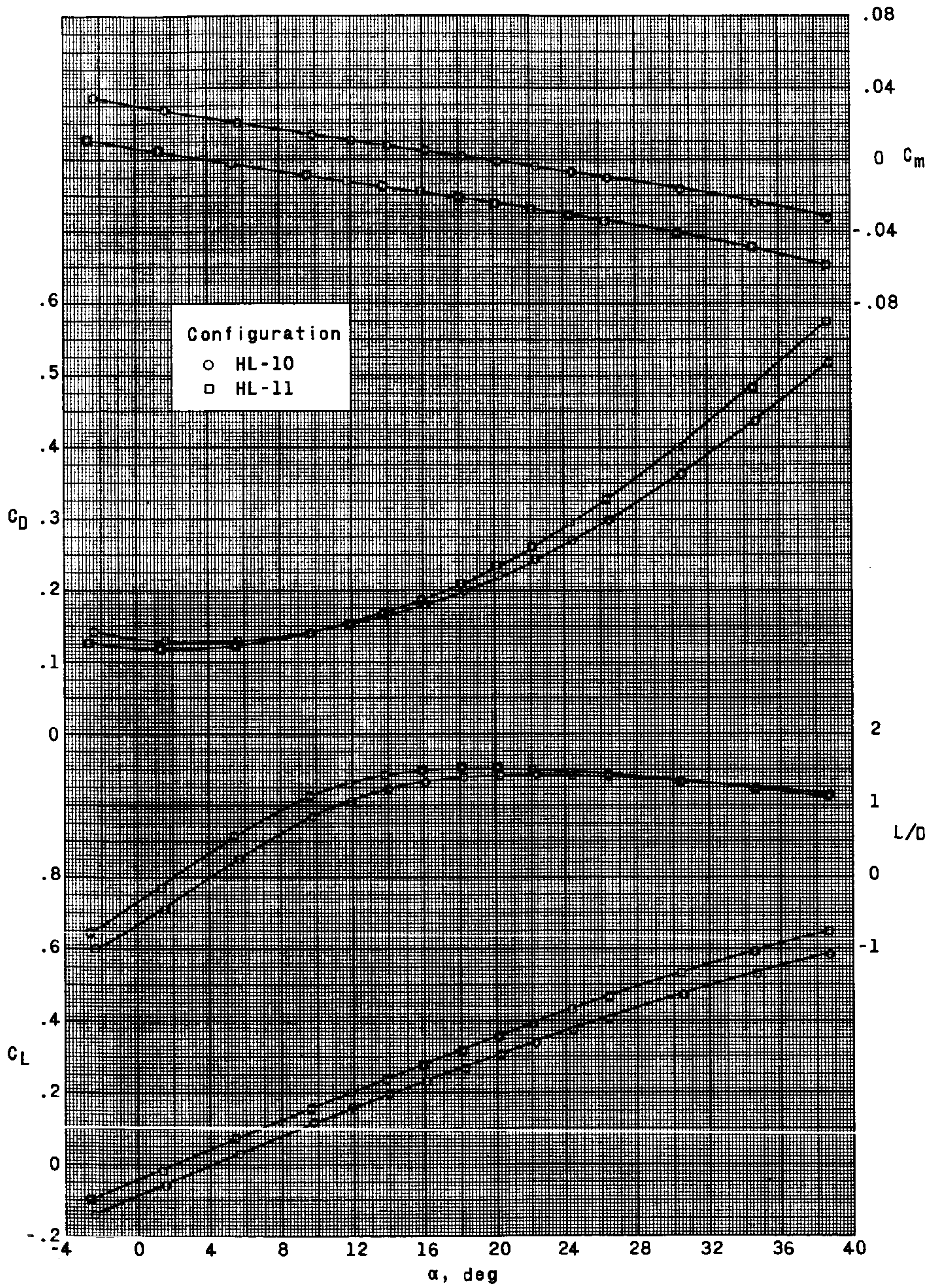


(b) M = 1.80.

Figure 7.- Continued.

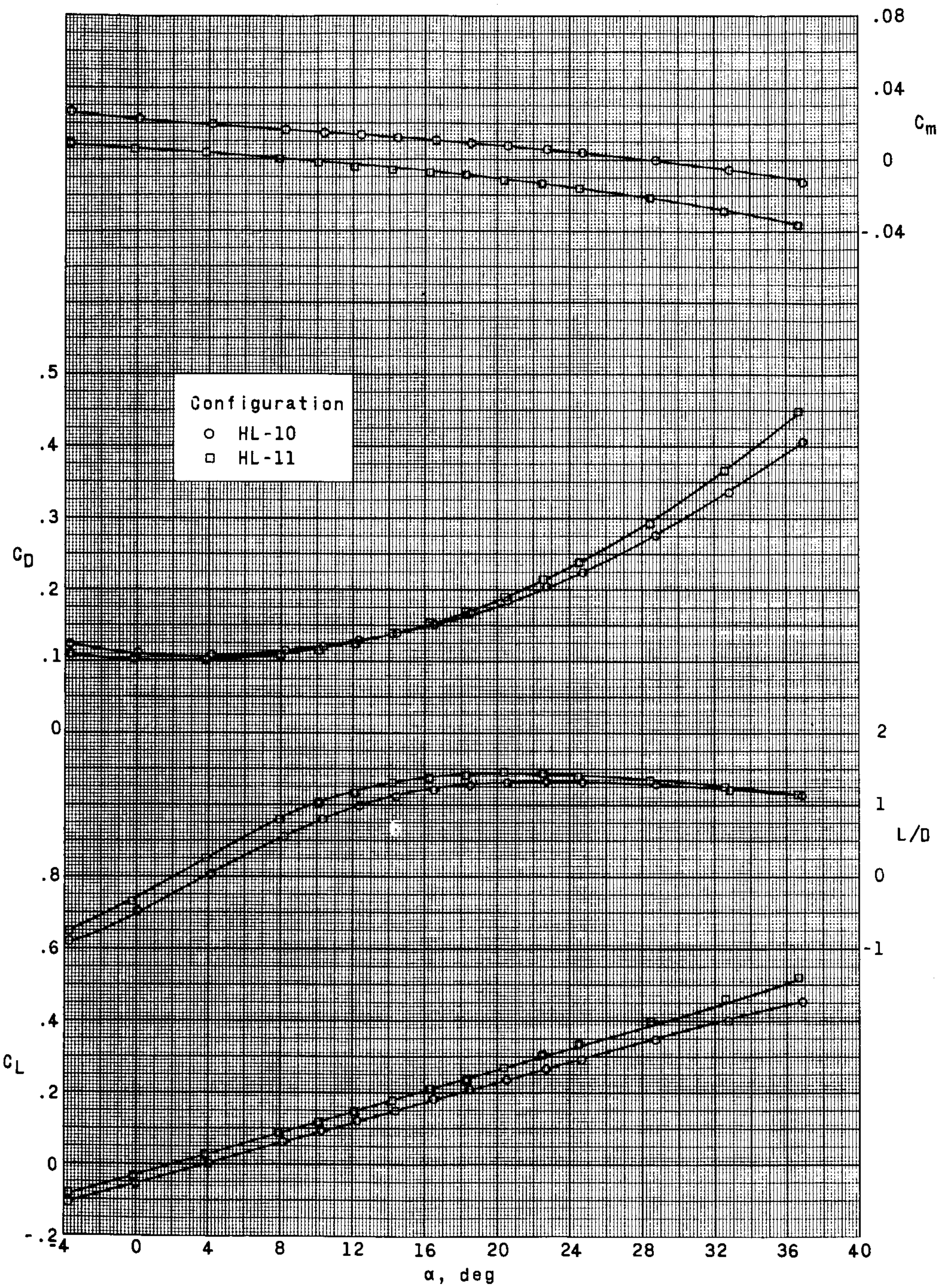
[redacted]

UNCLASSIFIED



(c) M = 2.16.

Figure 7.- Continued.

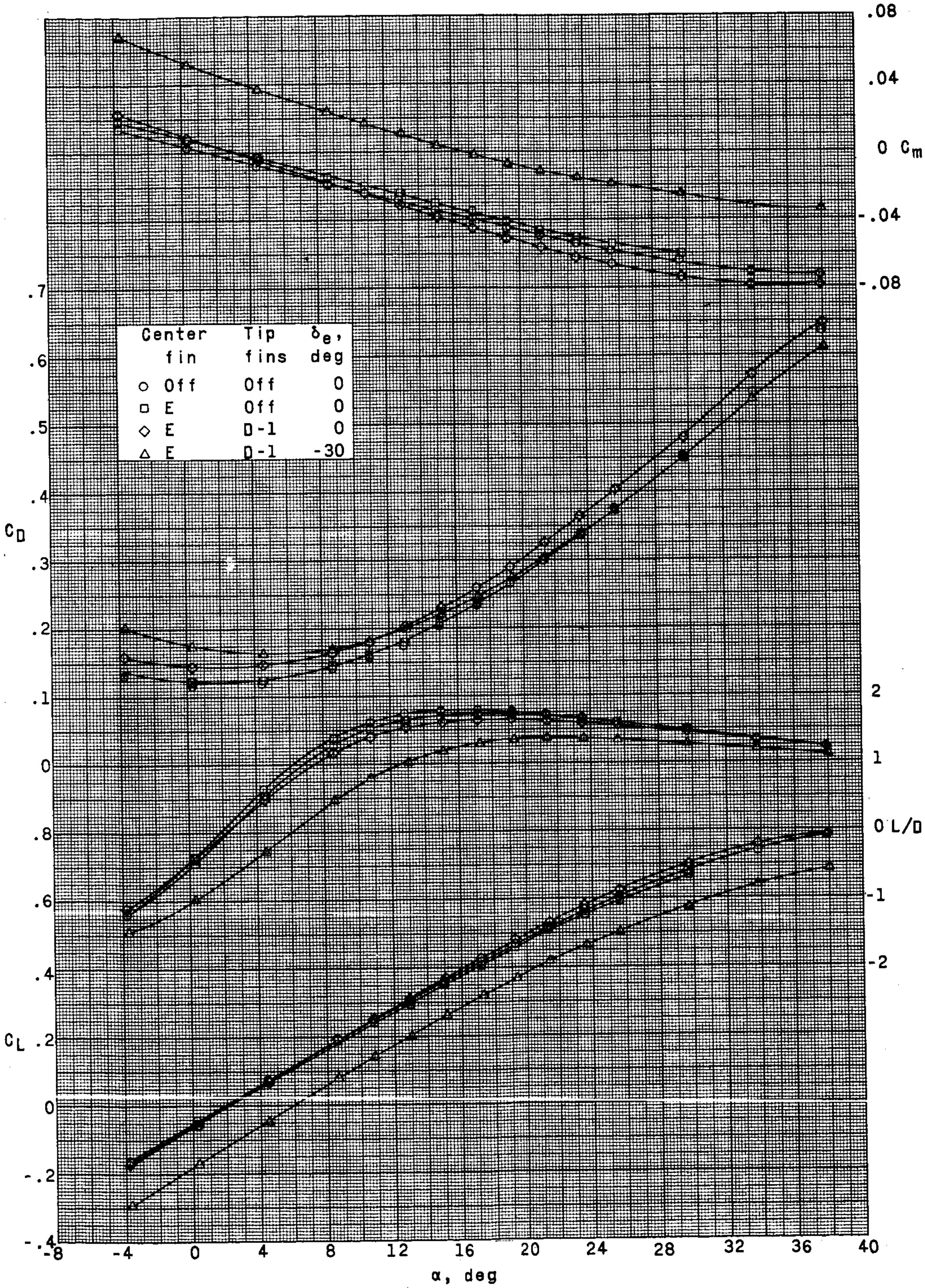


(d) M = 2.86.

Figure 7.- Concluded.

UNCLASSIFIED

[redacted]

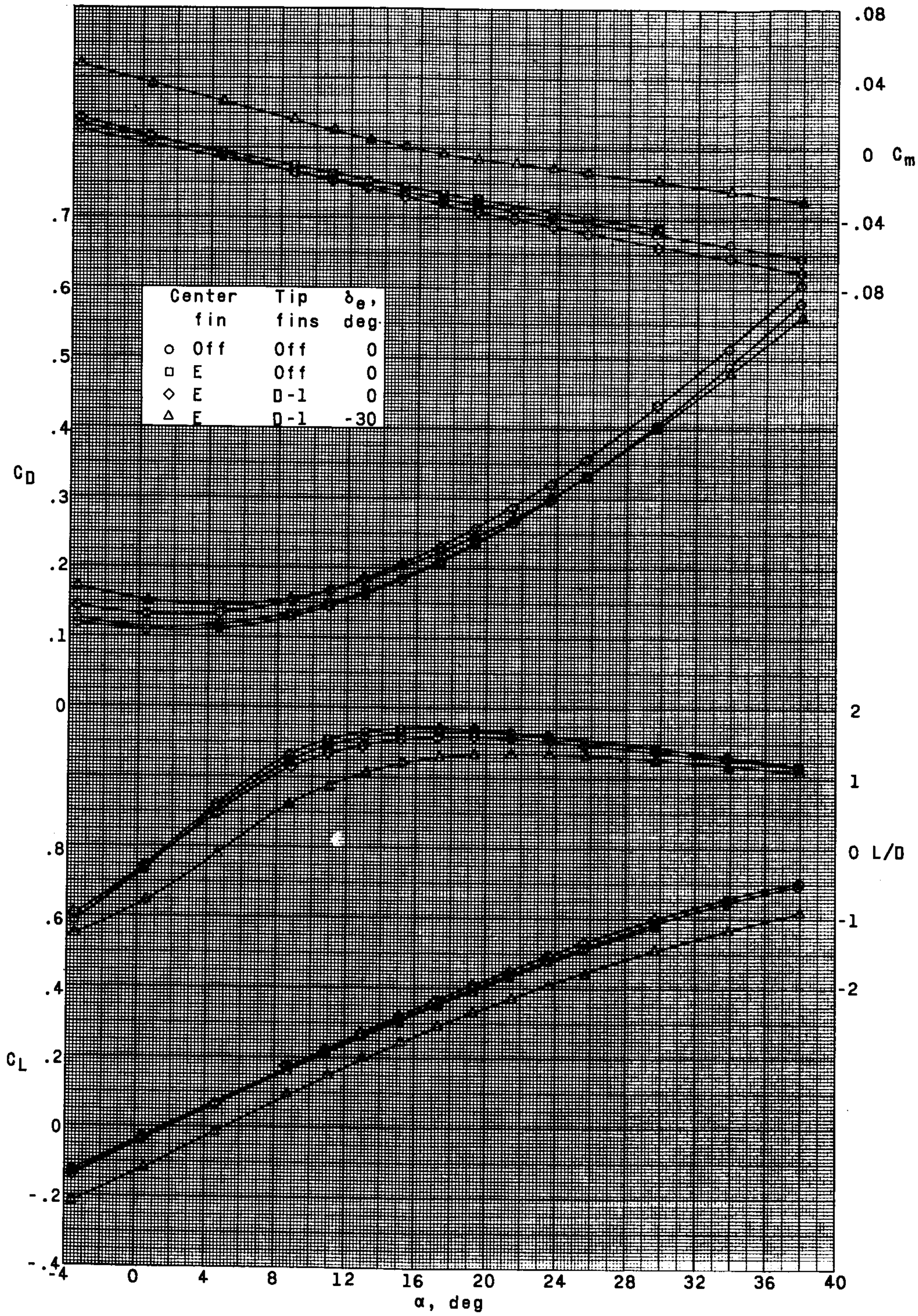


(a) M = 1.50.

Figure 8.- Effects of various configurations of HL-11 on longitudinal characteristics.

[redacted]

UNCLASSIFIED

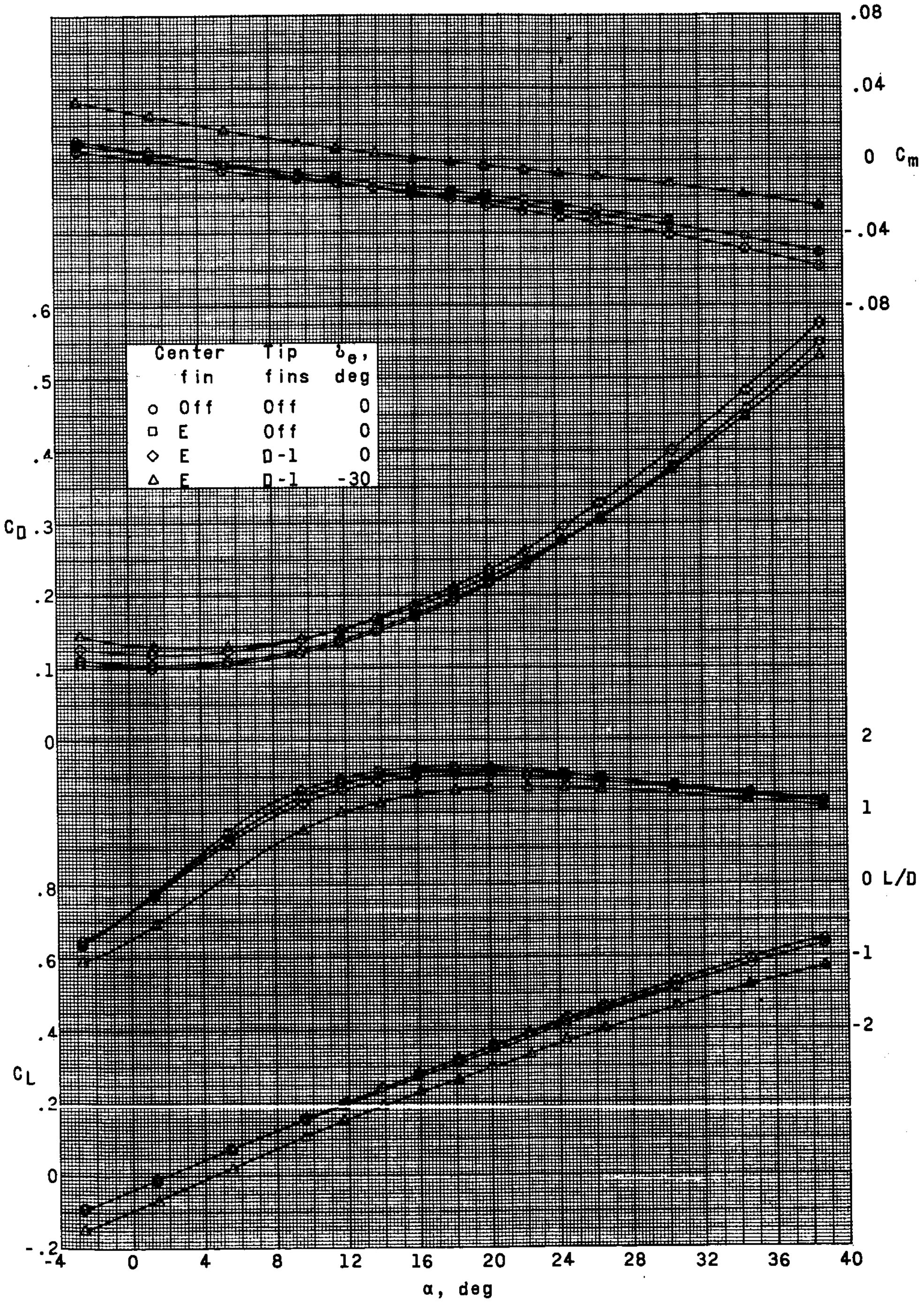


(b) $M = 1.80$.

Figure 8.- Continued

UNCLASSIFIED

[redacted]

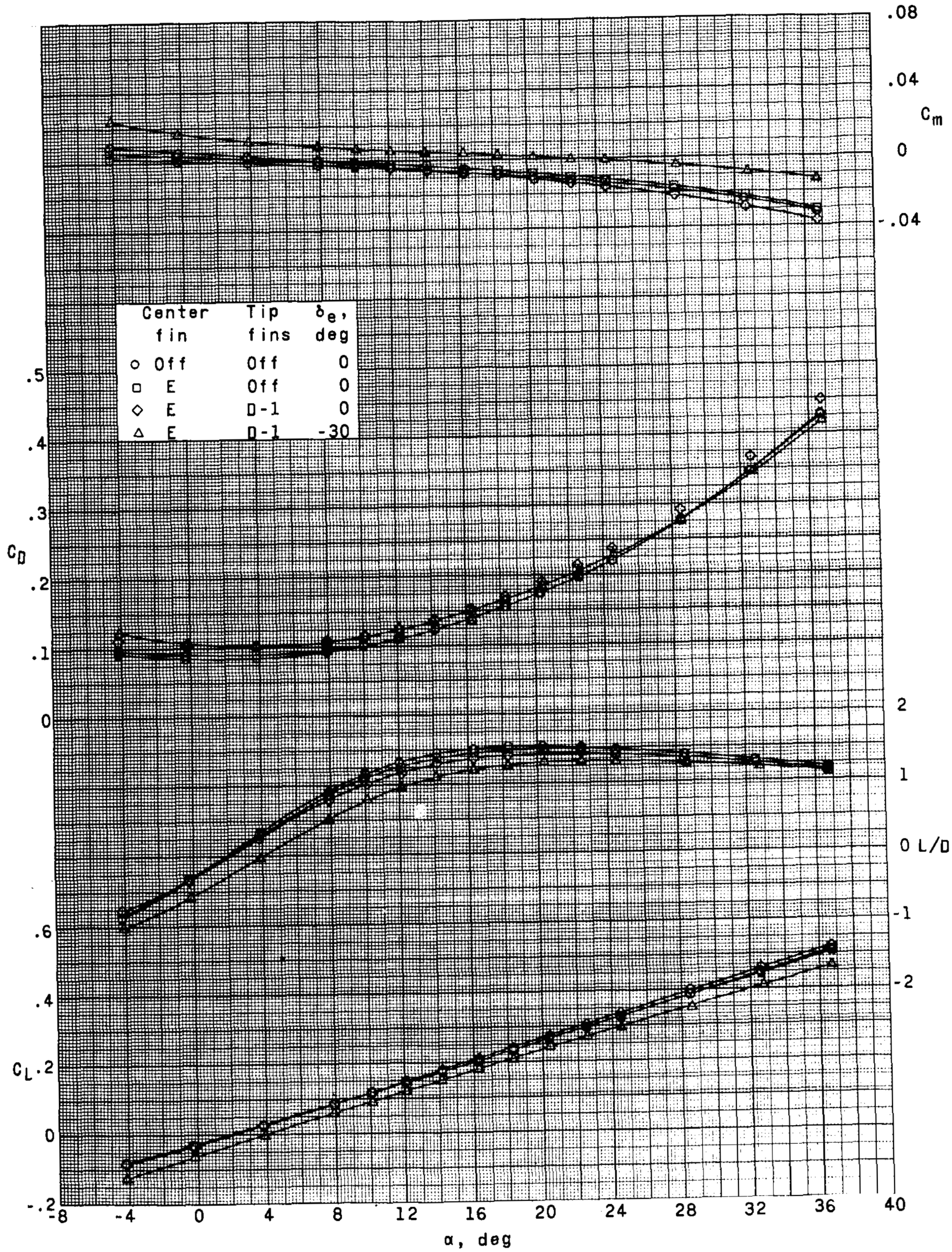


(c) M = 2.16.

Figure 8.- Continued.

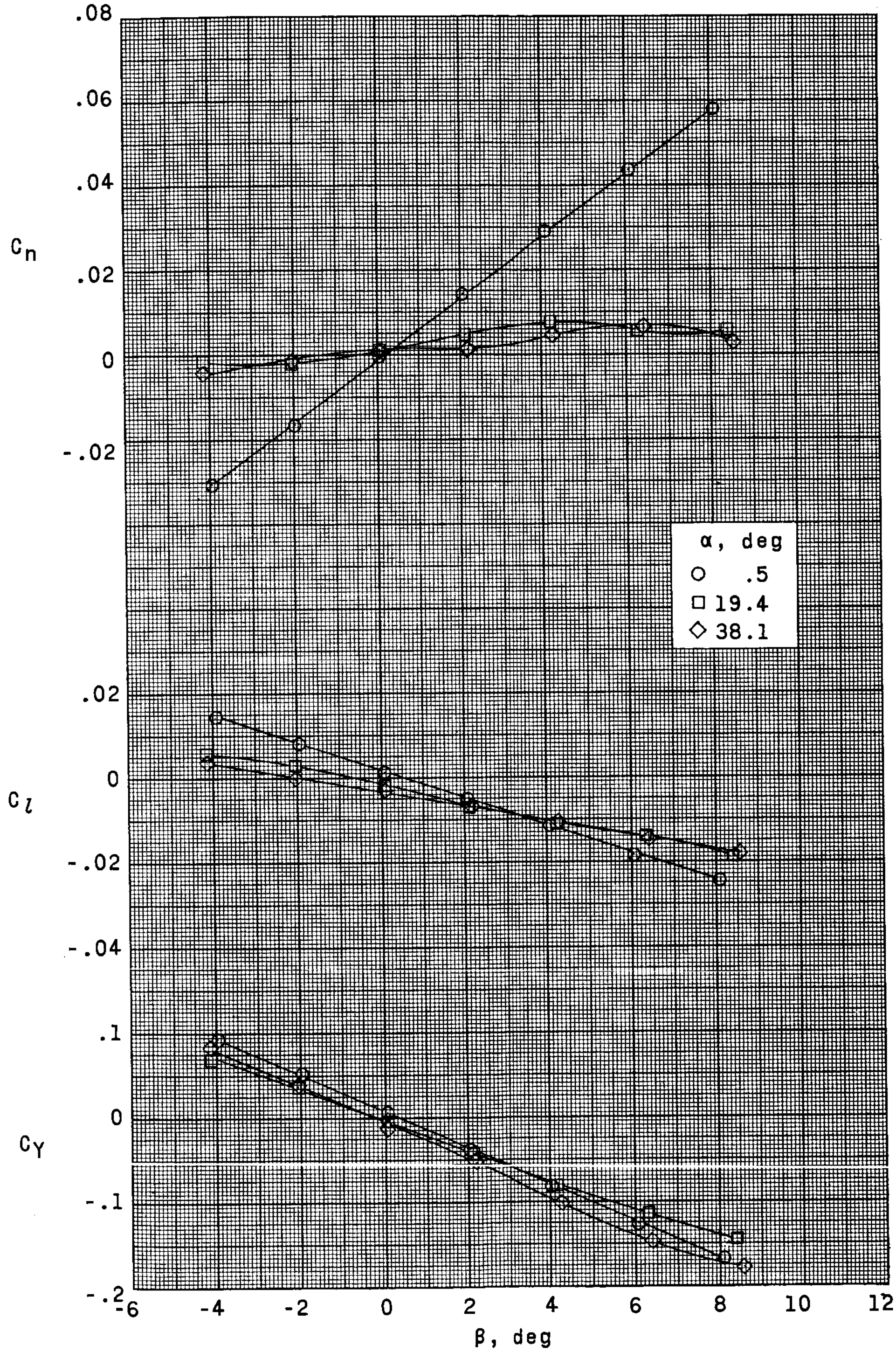
[redacted]

UNCLASSIFIED



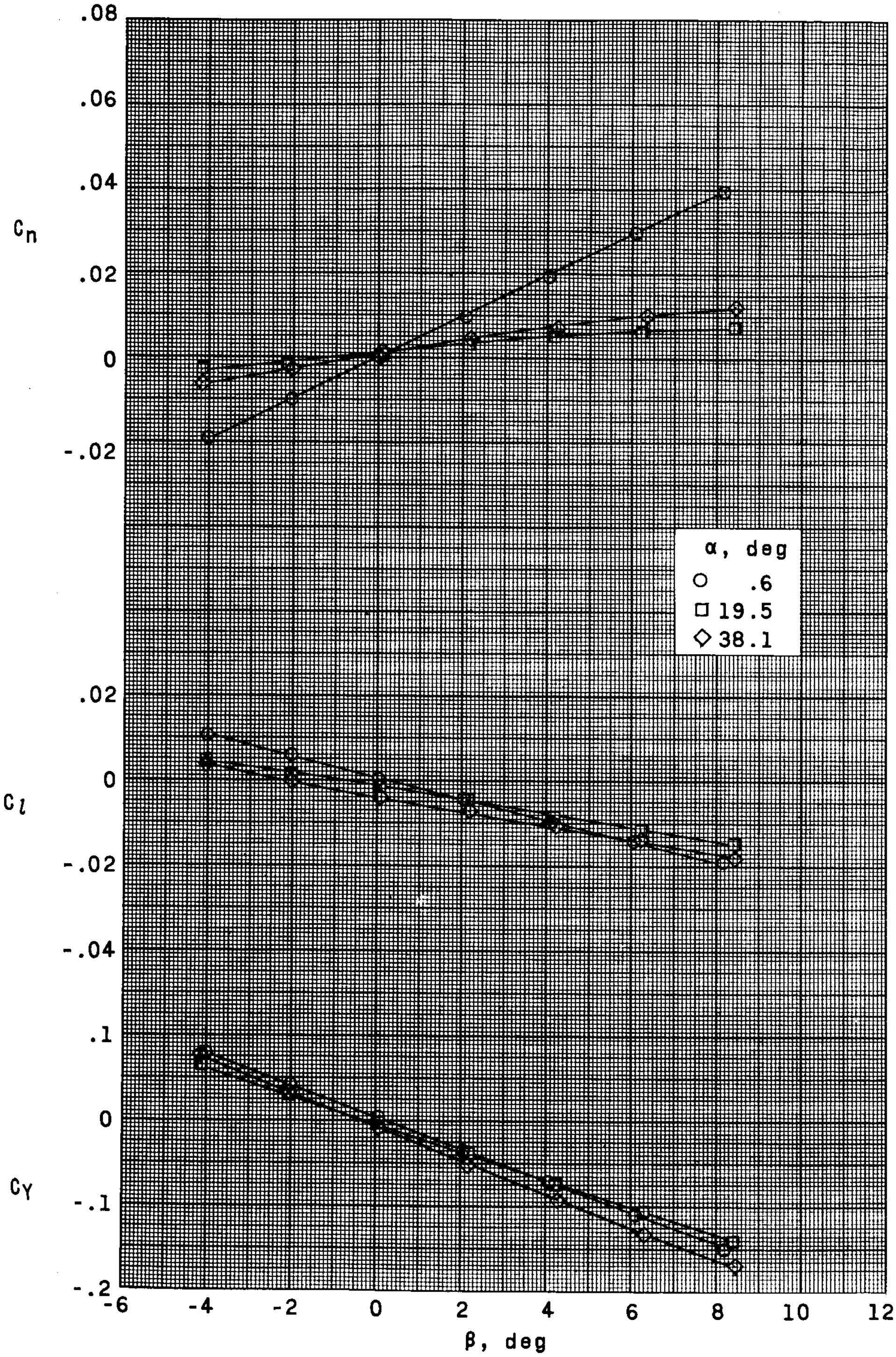
(d) M = 2.86.

Figure 8.- Concluded.



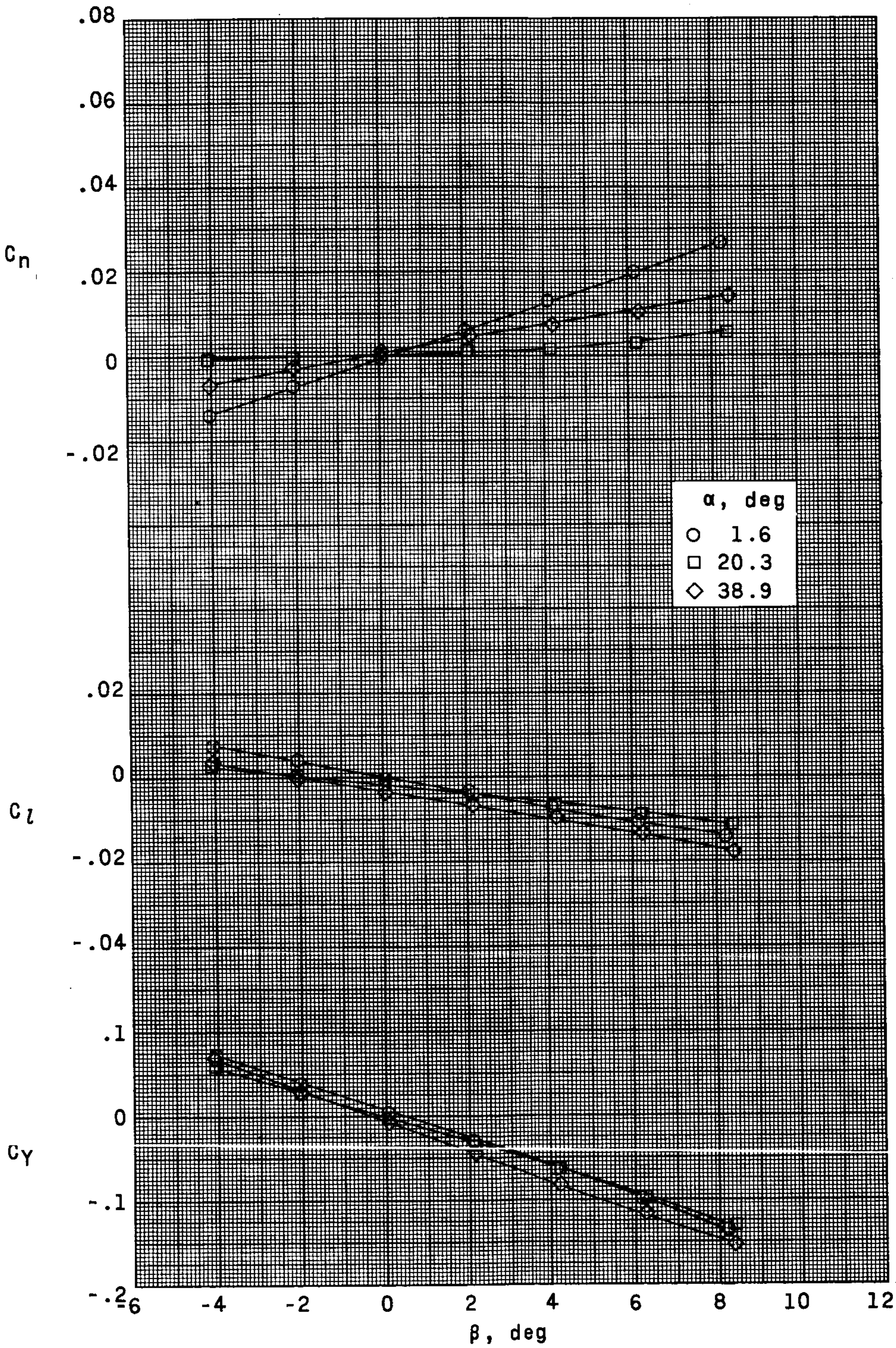
(a) M = 1.50.

Figure 9.- Basic sideslip characteristics of HL-10 with center fin E and tip fins P_1.



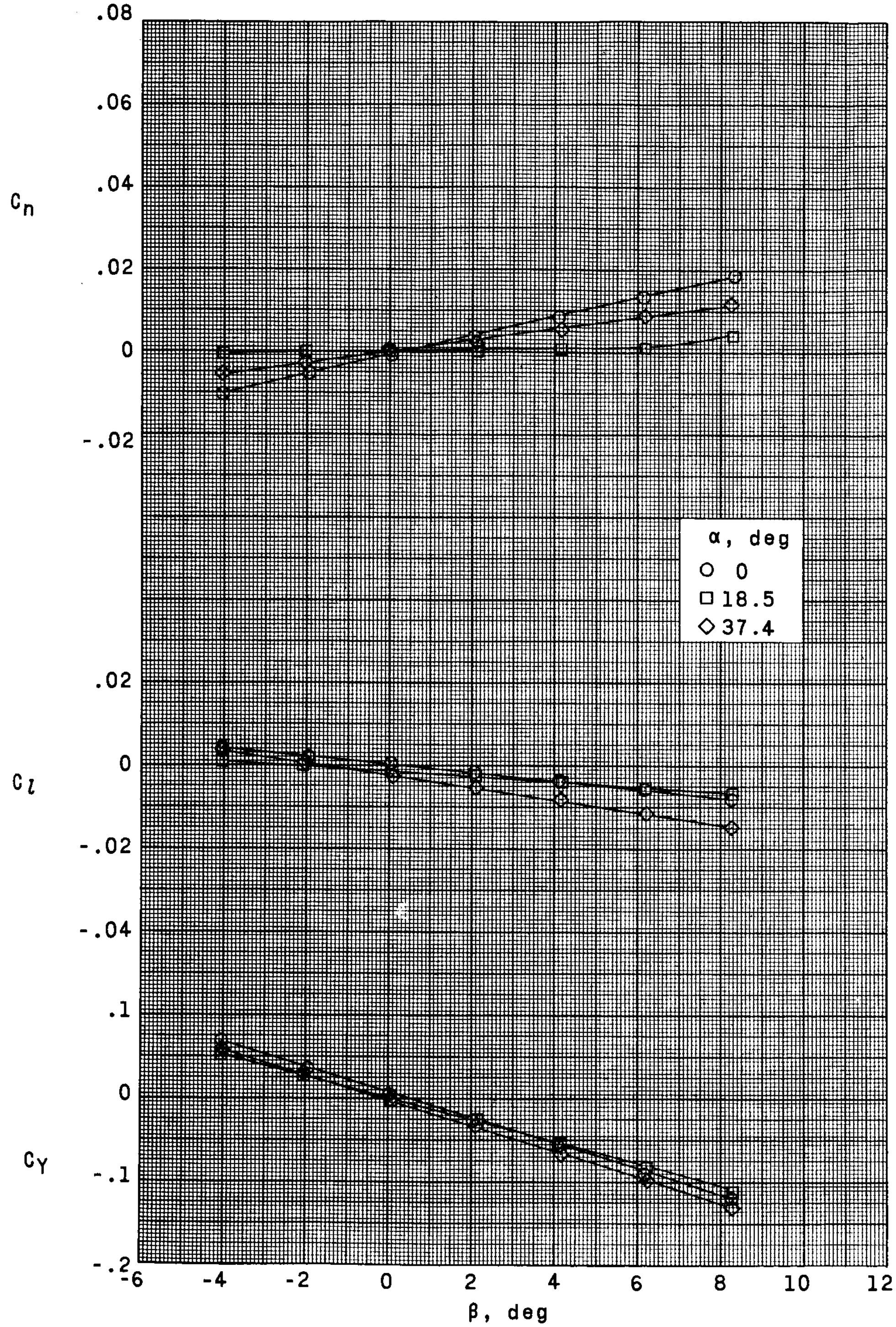
(b) M = 1.80.

Figure 9.- Continued.



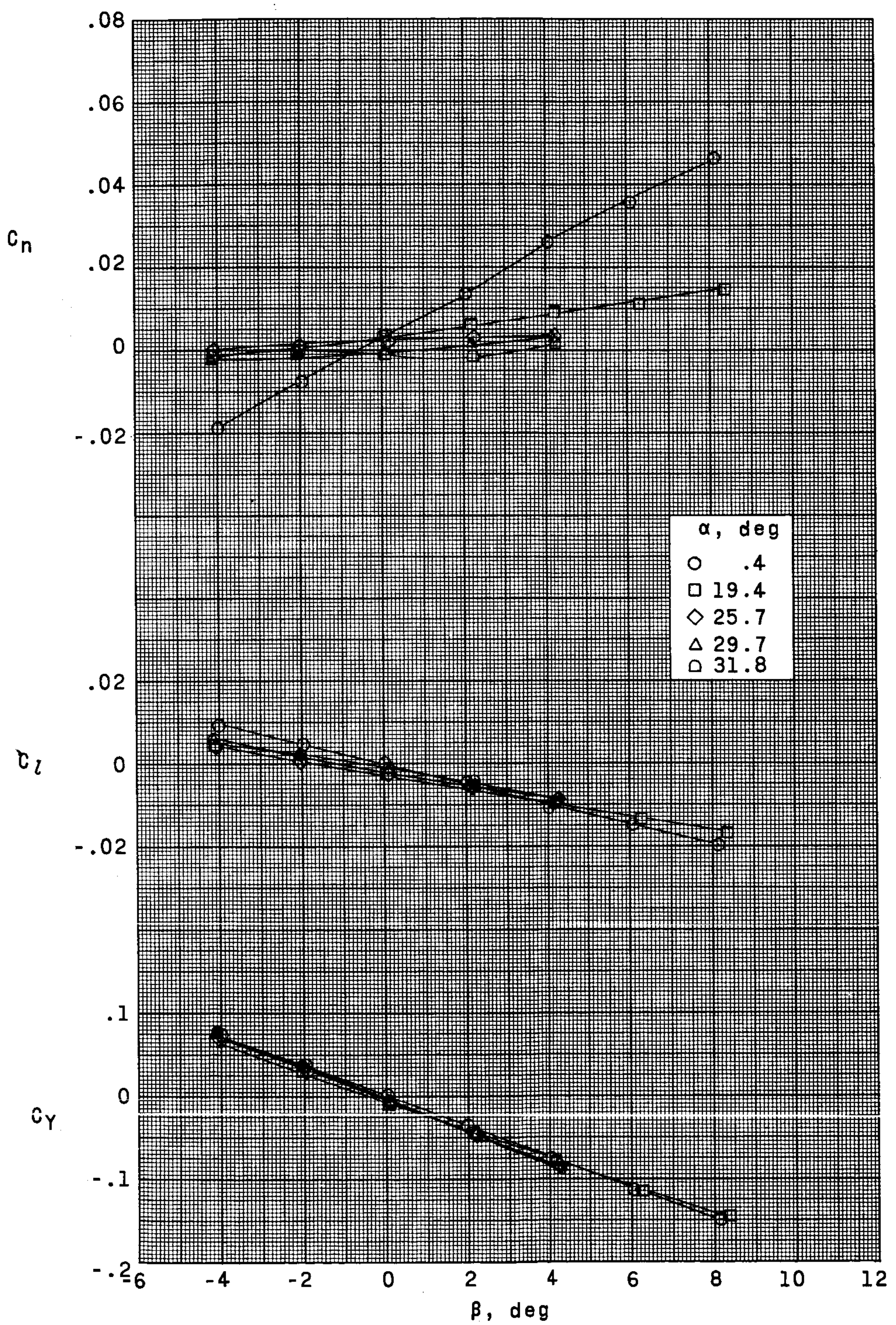
(c) M = 2.16.

Figure 9.- Continued.



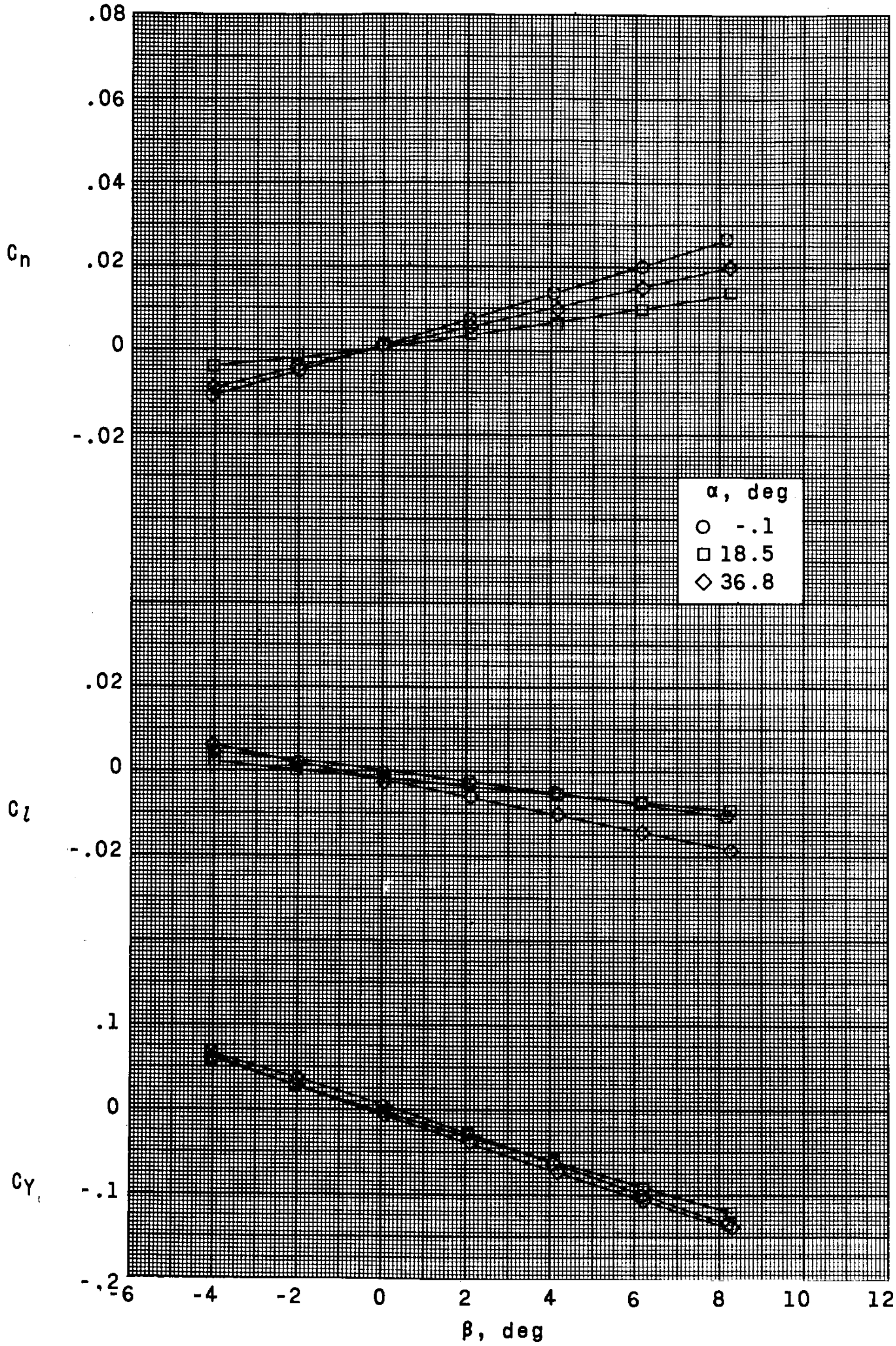
(d) M = 2.86.

Figure 9.- Concluded.



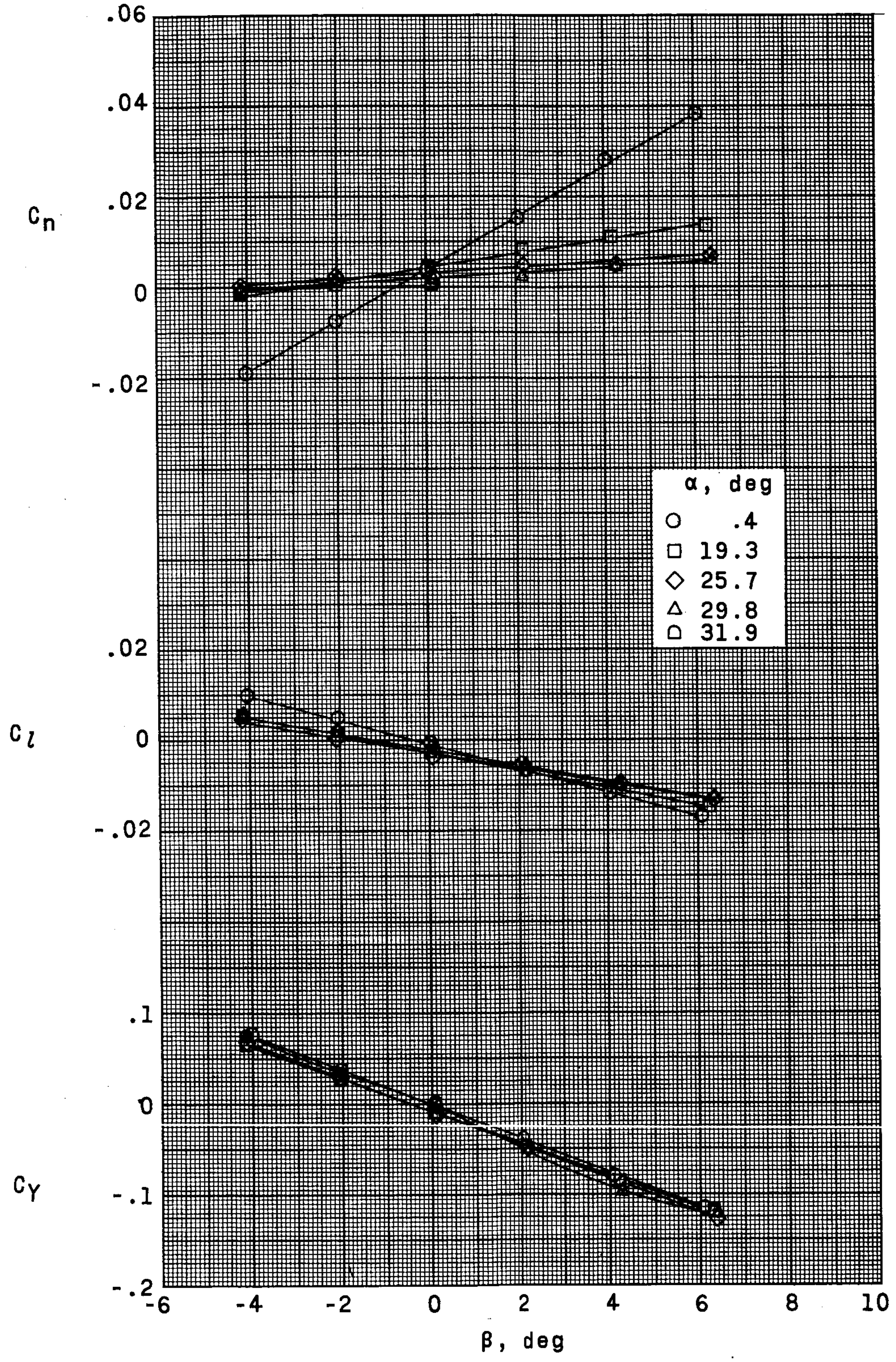
(a) M = 1.50.

Figure 10.- Basic sideslip characteristics of HL-10 with center fin E and tip fins I_2.



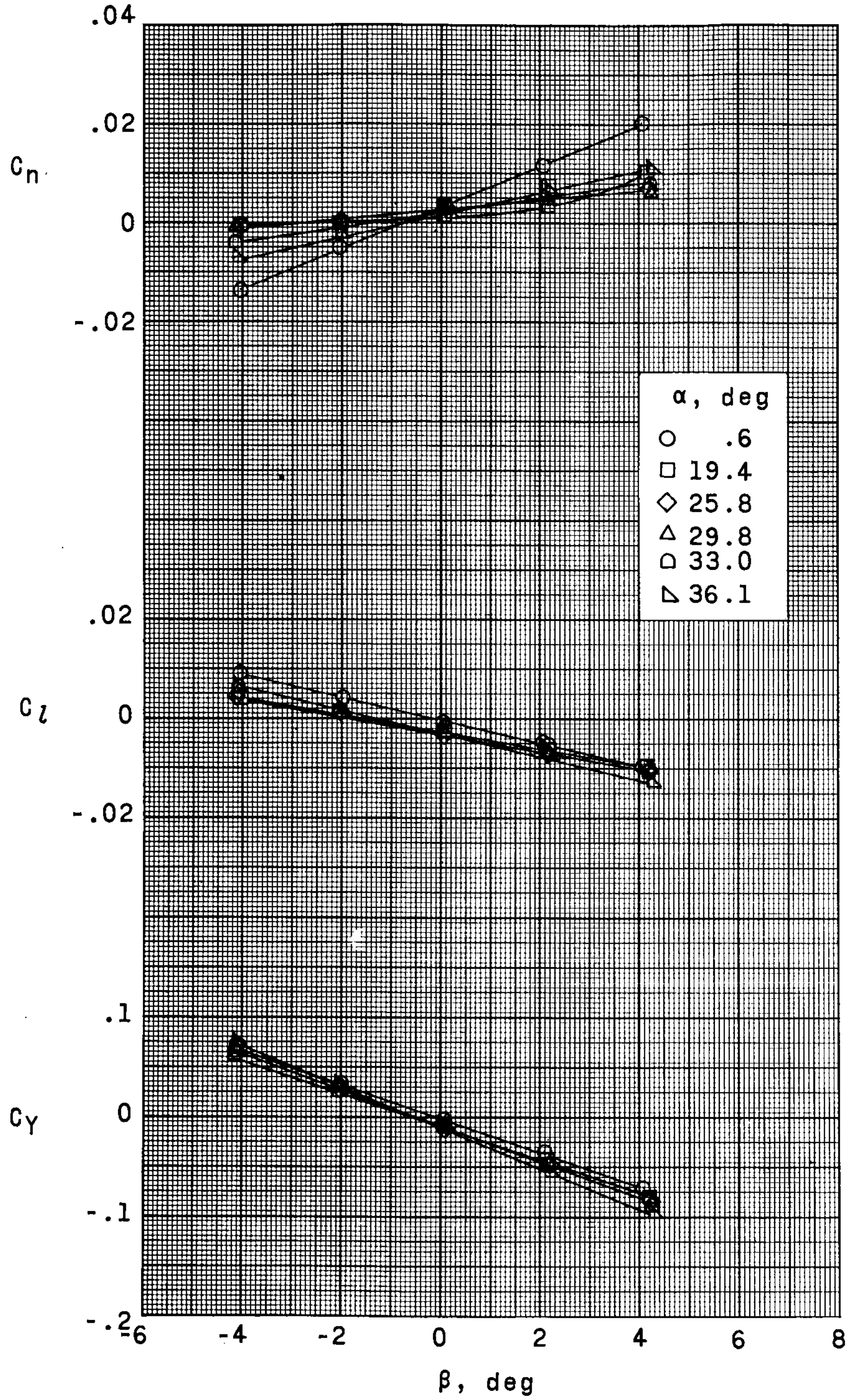
(b) M = 2.86.

Figure 10.- Concluded.



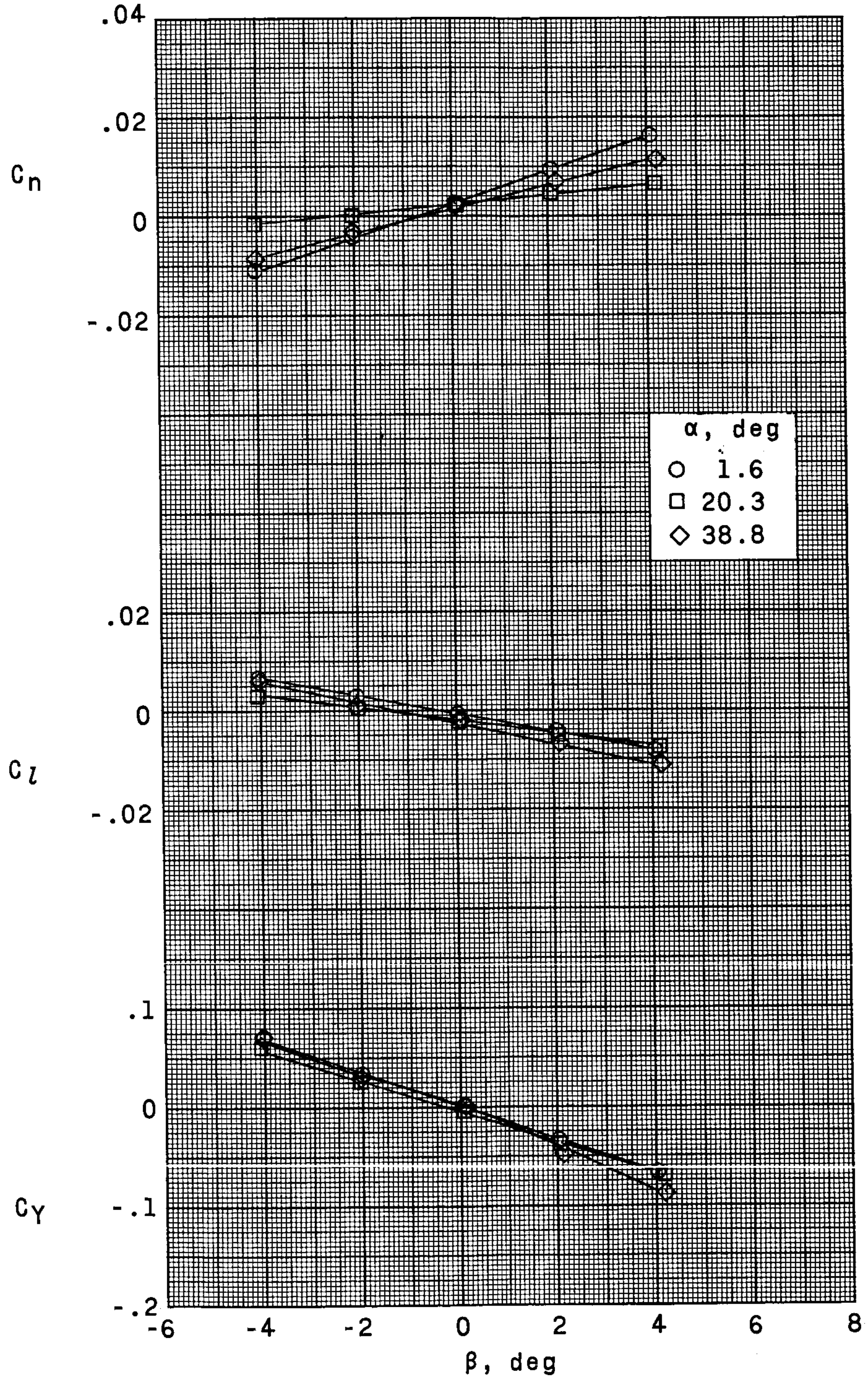
(a) M = 1.50.

Figure 11.- Basic sideslip characteristics of HL-10 with center fin E_1 and tip fins I_2.



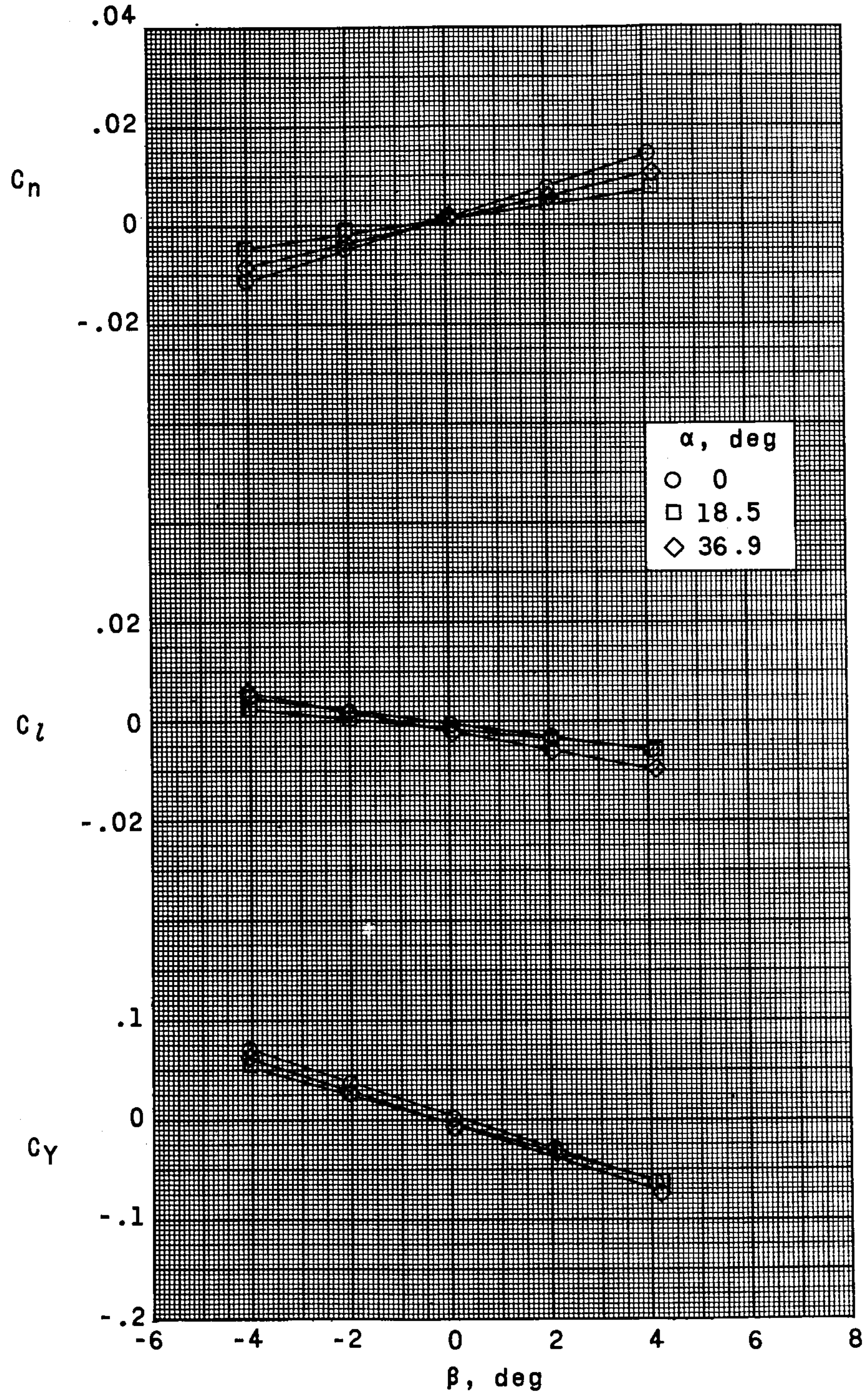
(b) M = 1.80.

Figure 11.- Continued.



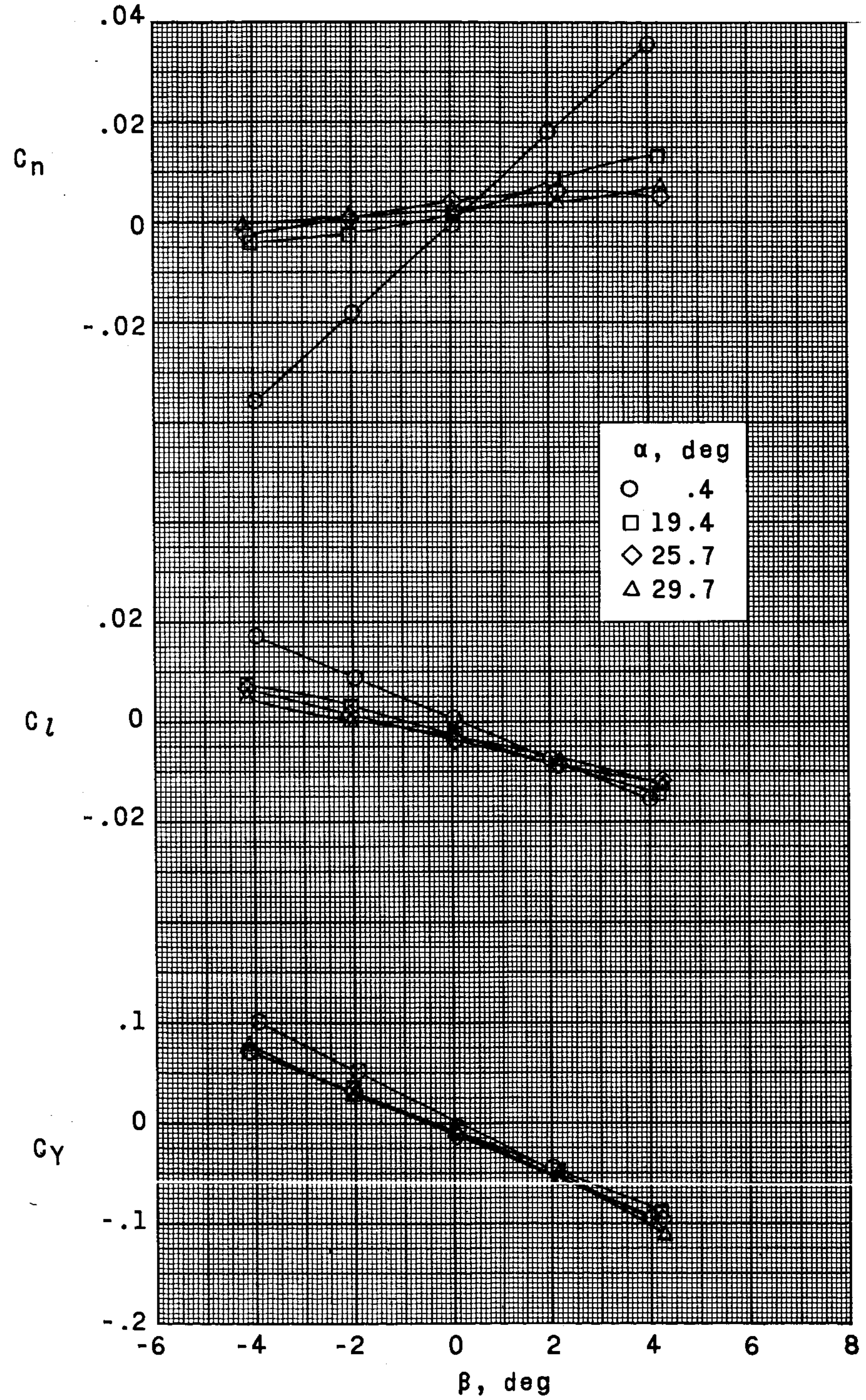
(c) M = 2.16.

Figure 11.- Continued.



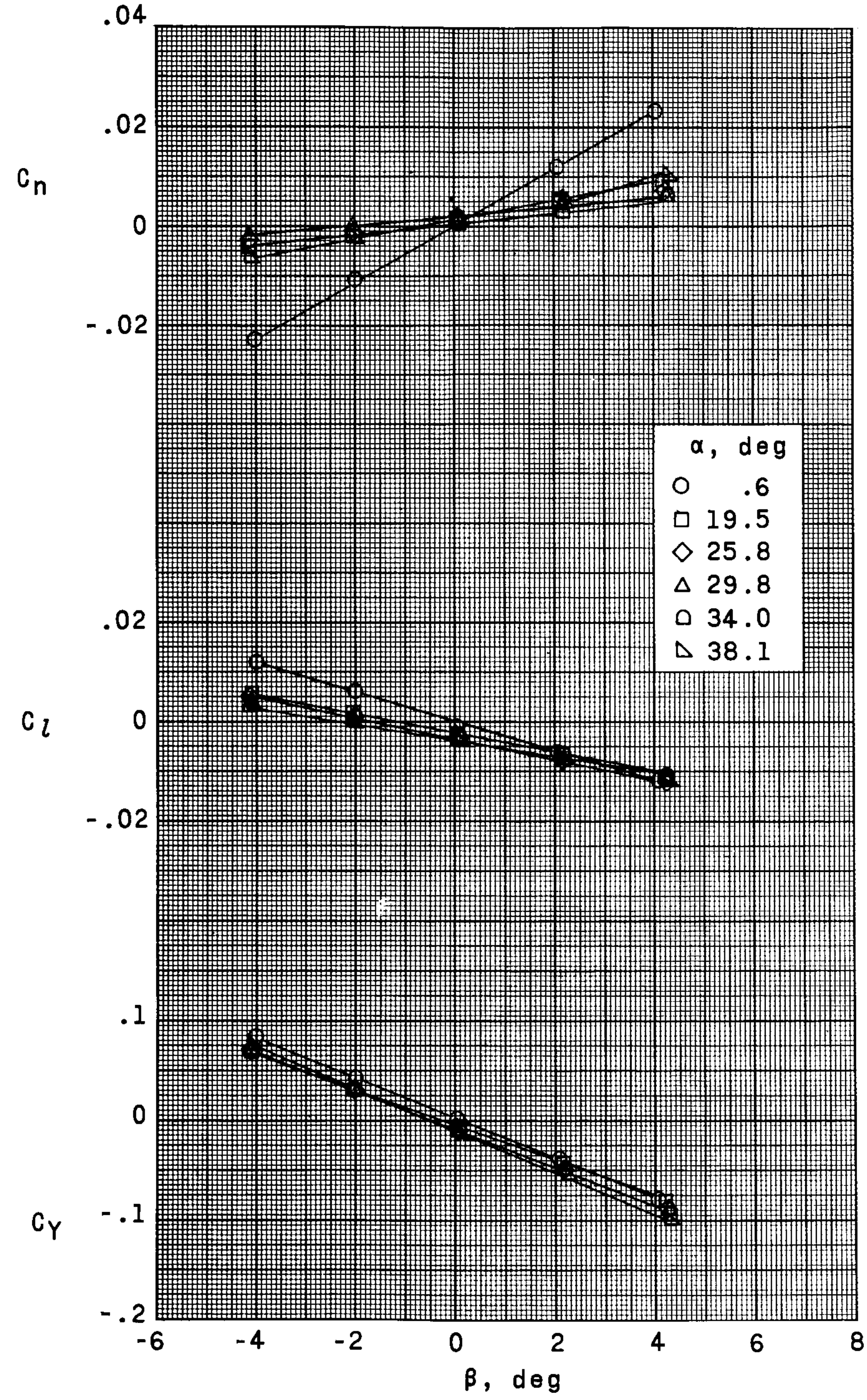
(d) M = 2.86.

Figure 11.- Concluded.



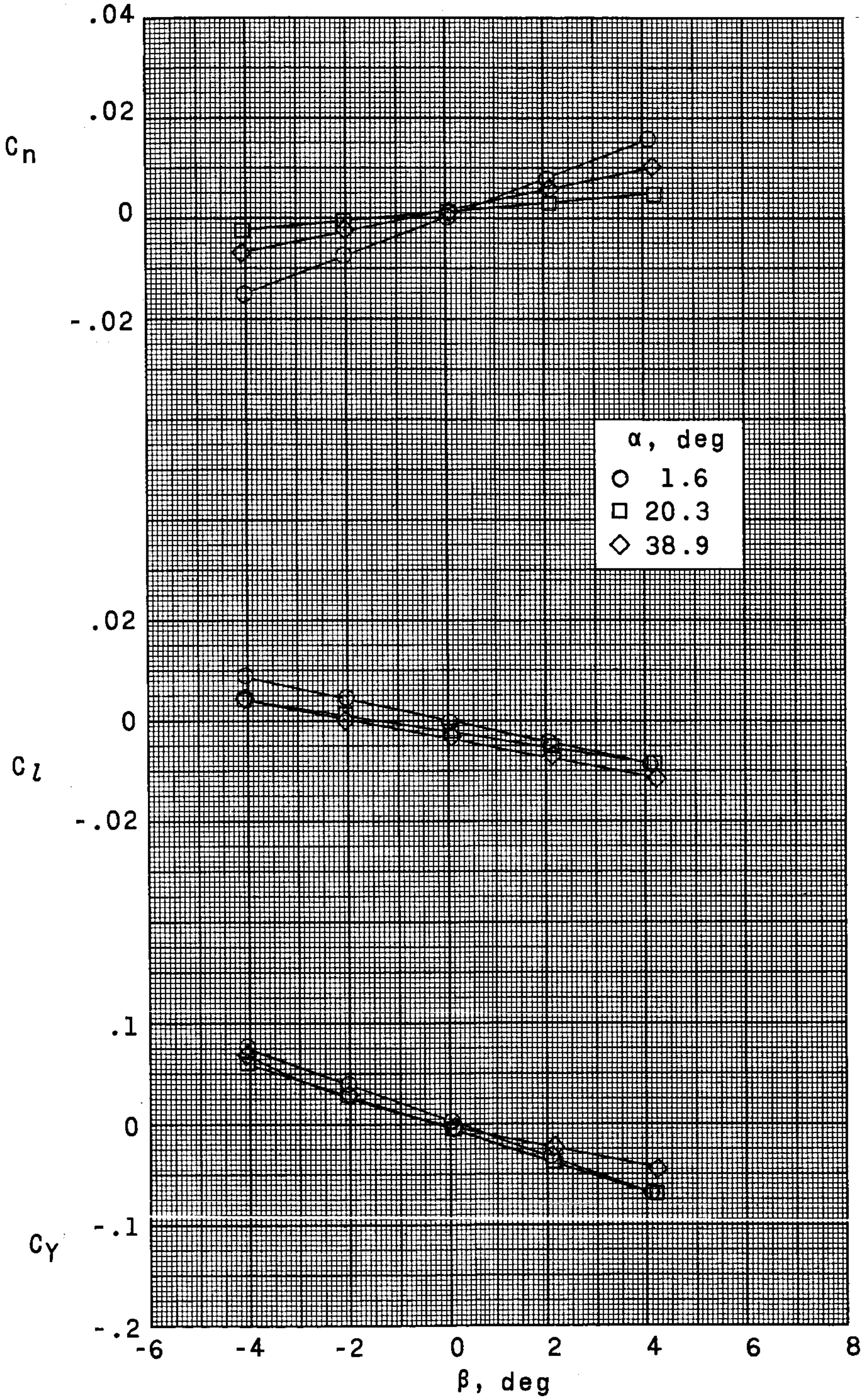
(a) M = 1.50.

Figure 12.- Basic sideslip characteristics of HL-10 with center fin E_2 and tip fins P_1.



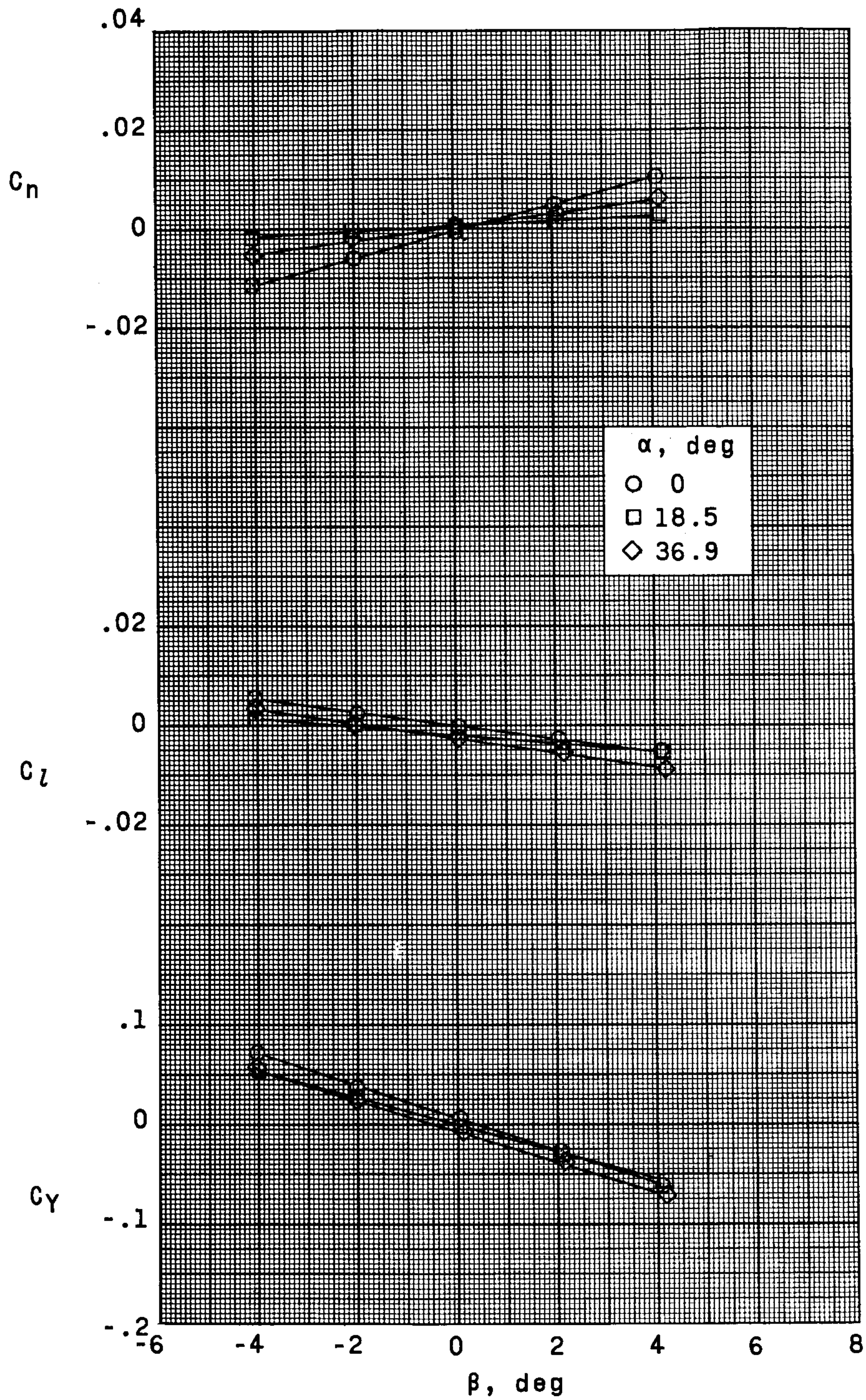
(b) M = 1.80.

Figure 12.- Continued.



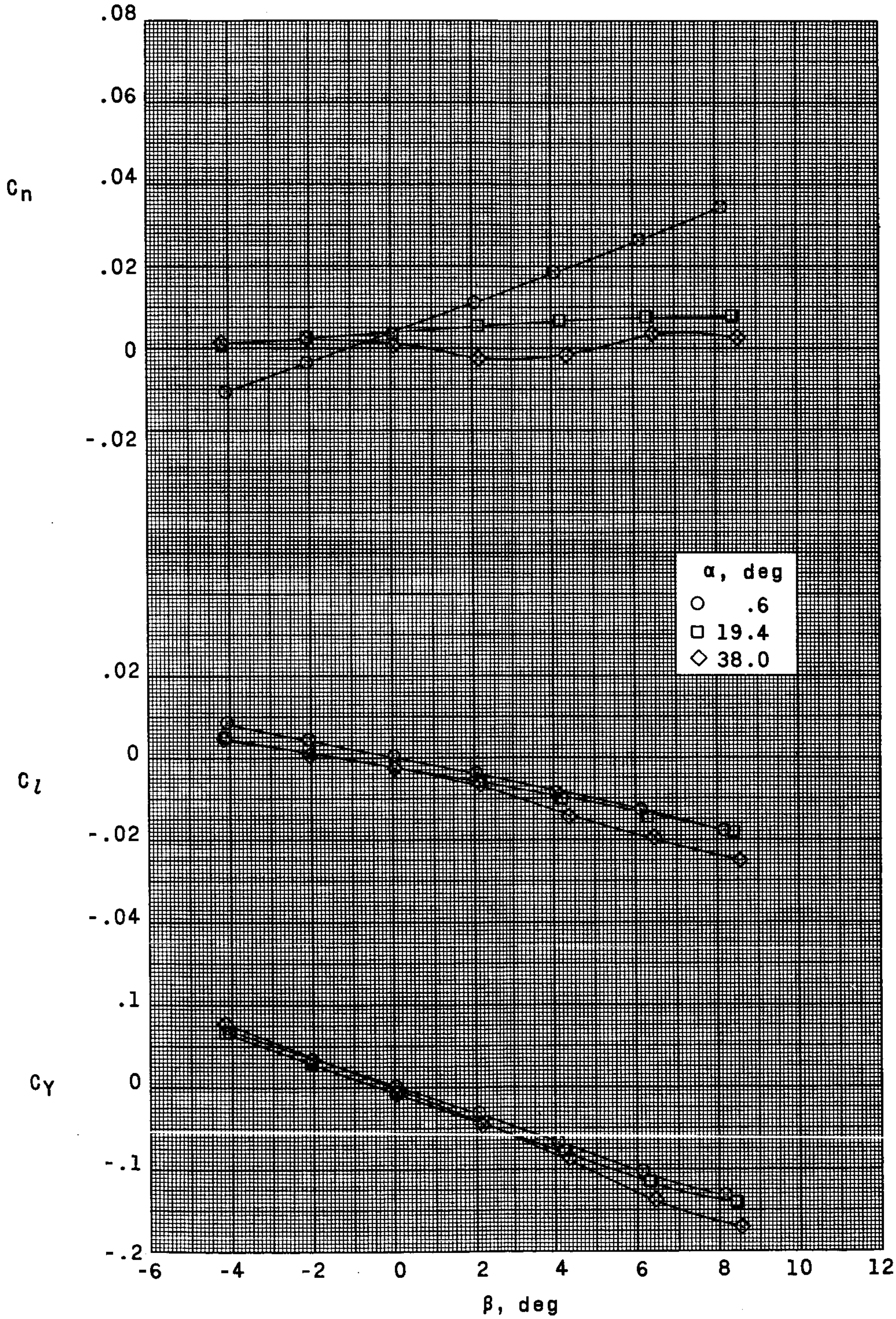
(c) M = 2.16.

Figure 12.- Continued.



(d) M = 2.86.

Figure 12.- Concluded.



(a) M = 1.50.

Figure 13.- Basic sideslip characteristics of HL-10 with center fin E_2 and tip fins D-1.

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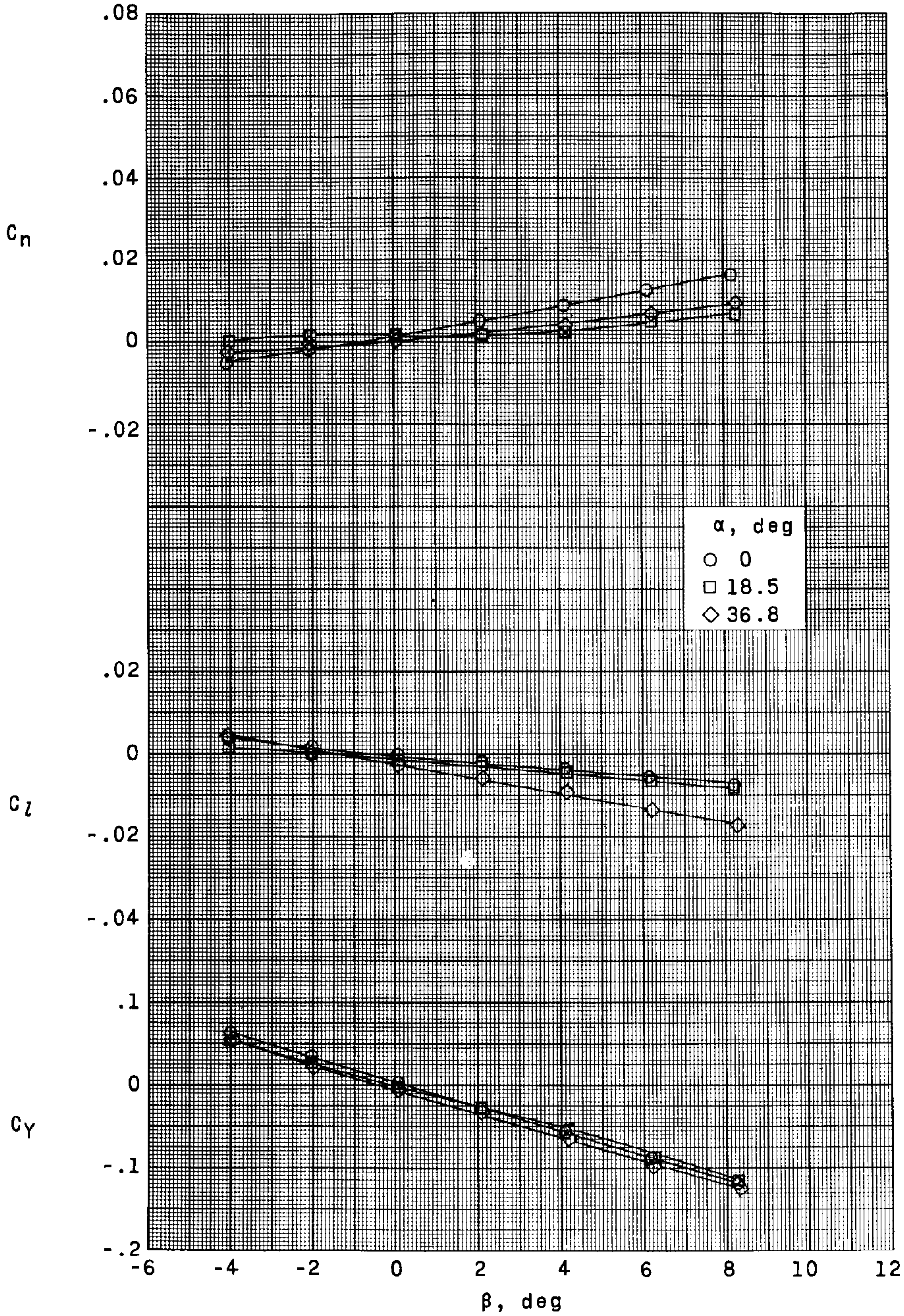
[redacted]

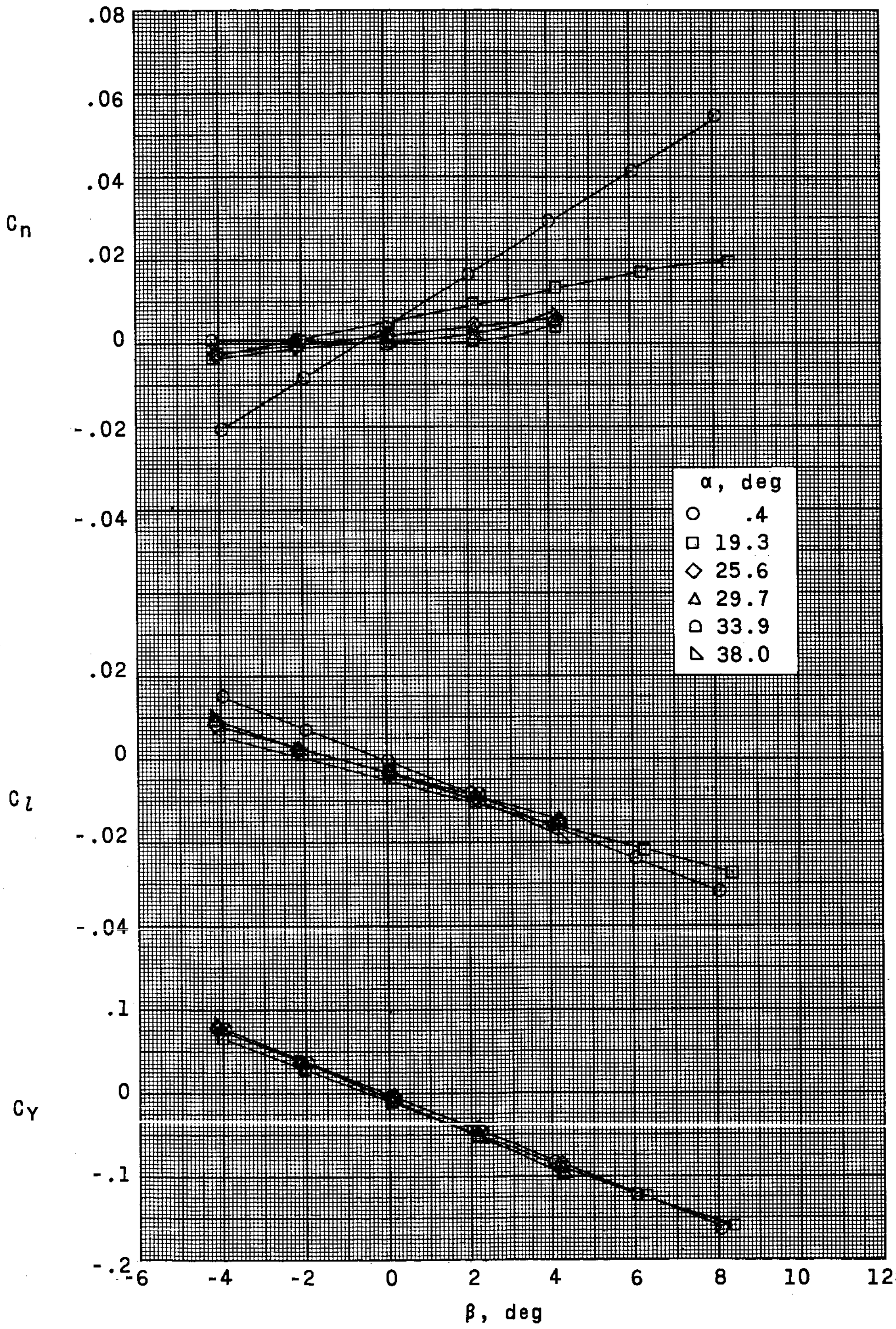


(b) M = 2.86.

Figure 13.- Concluded.

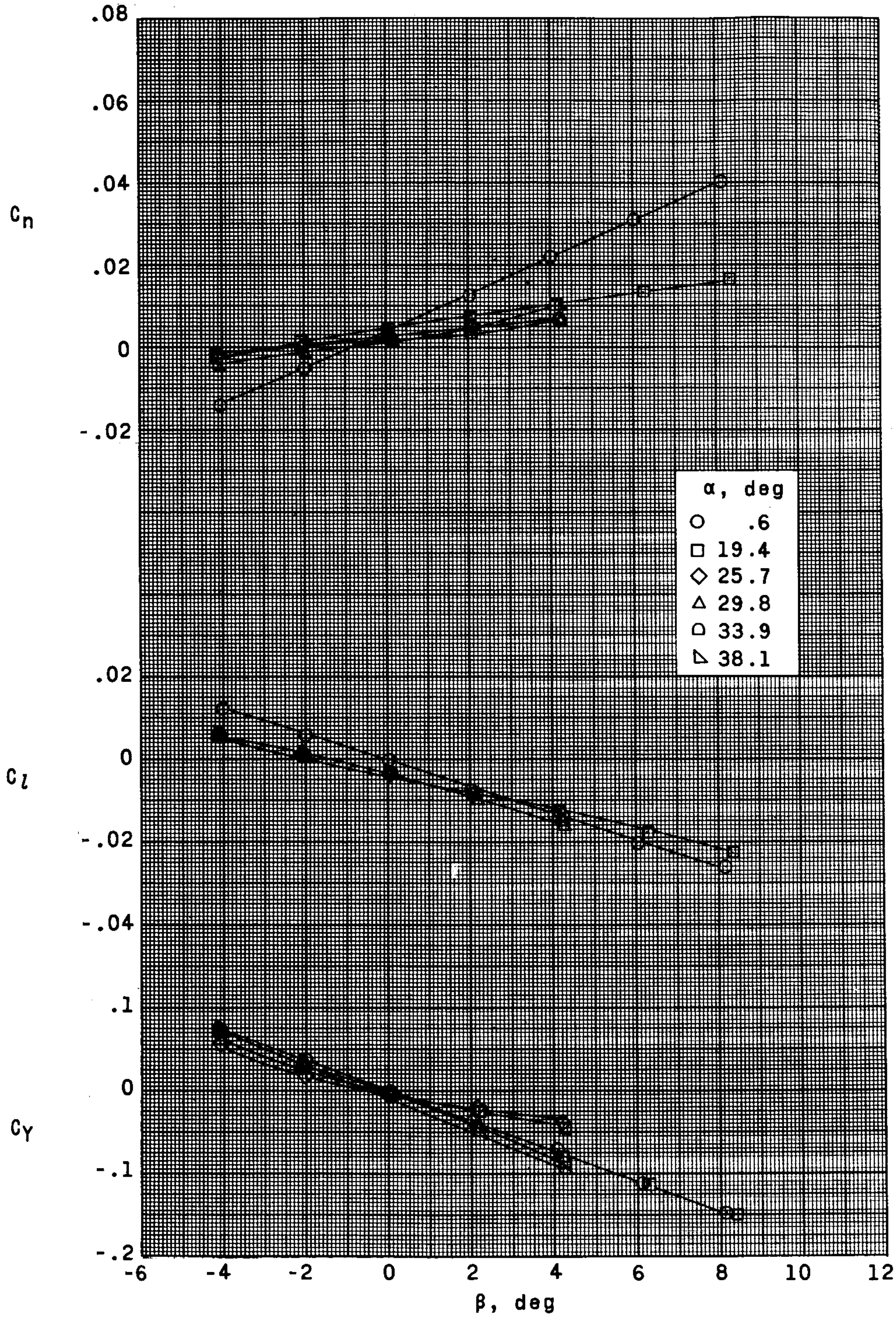
[redacted]

UNCLASSIFIED



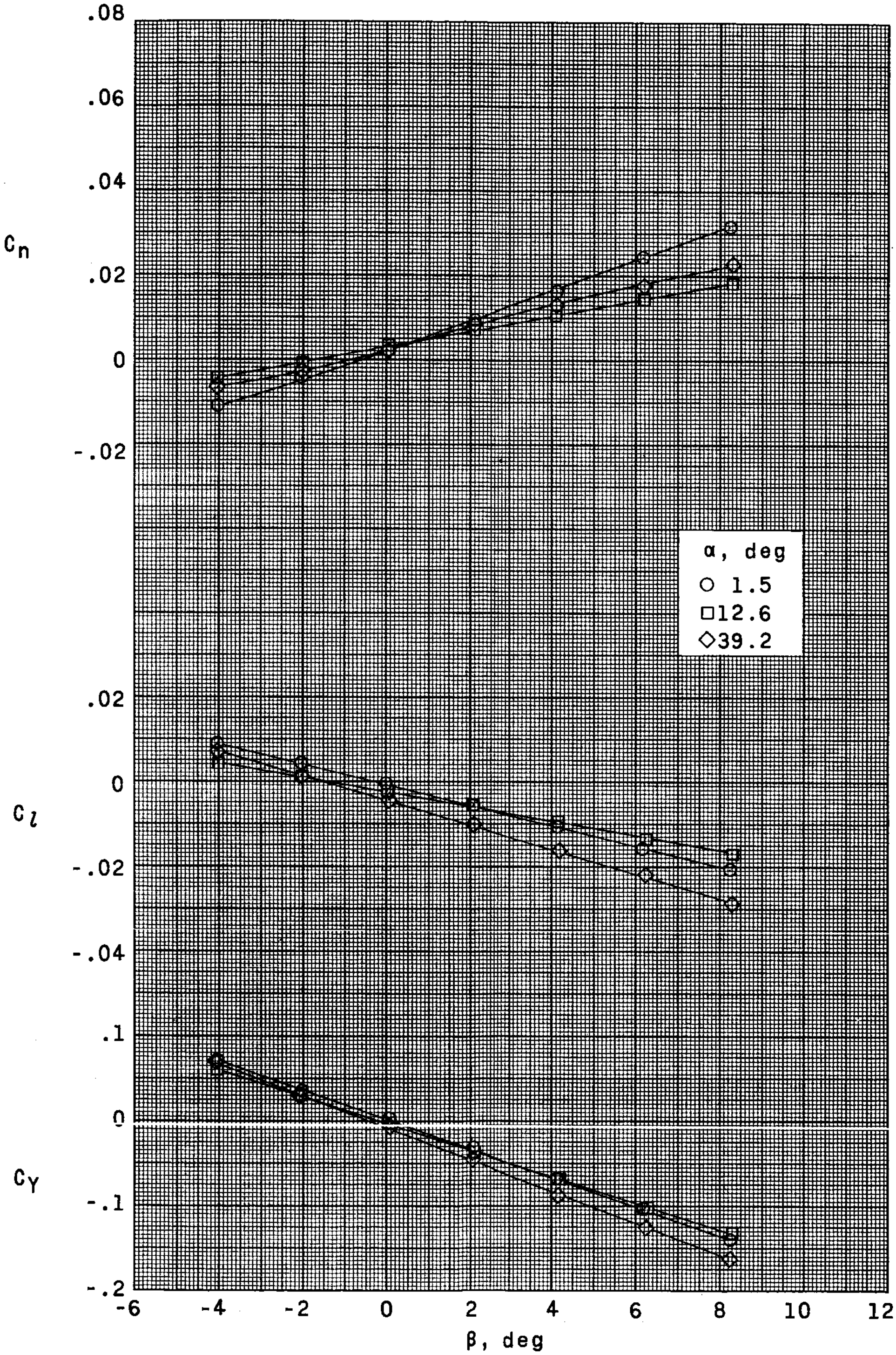
(a) M = 1.50.

Figure 14.- Basic sideslip characteristics of HL-10 with center fin E_2 and tip fins I_1.



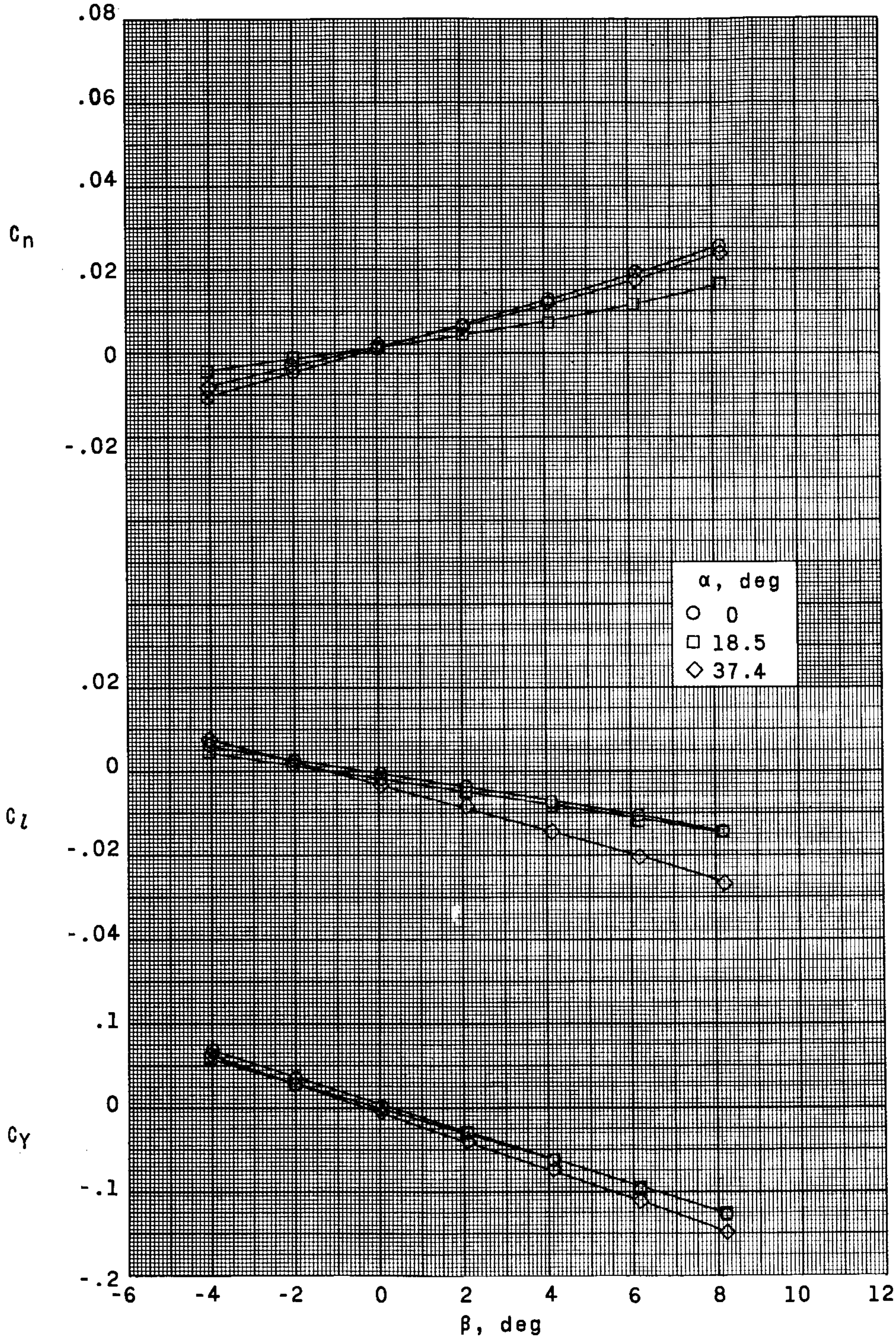
(b) M = 1.80.

Figure 14.- Continued.



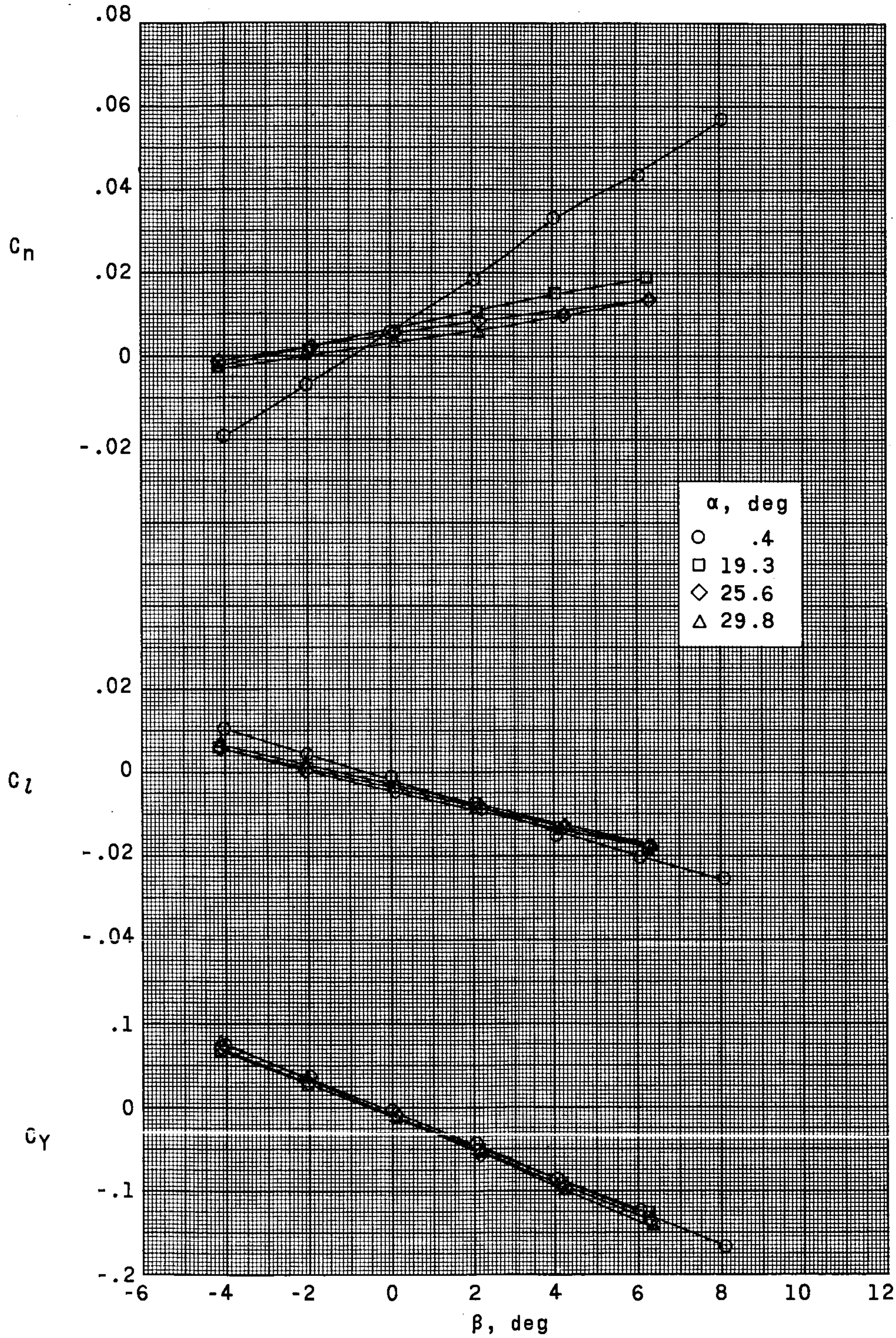
(c) M = 2.16.

Figure 14.- Continued.



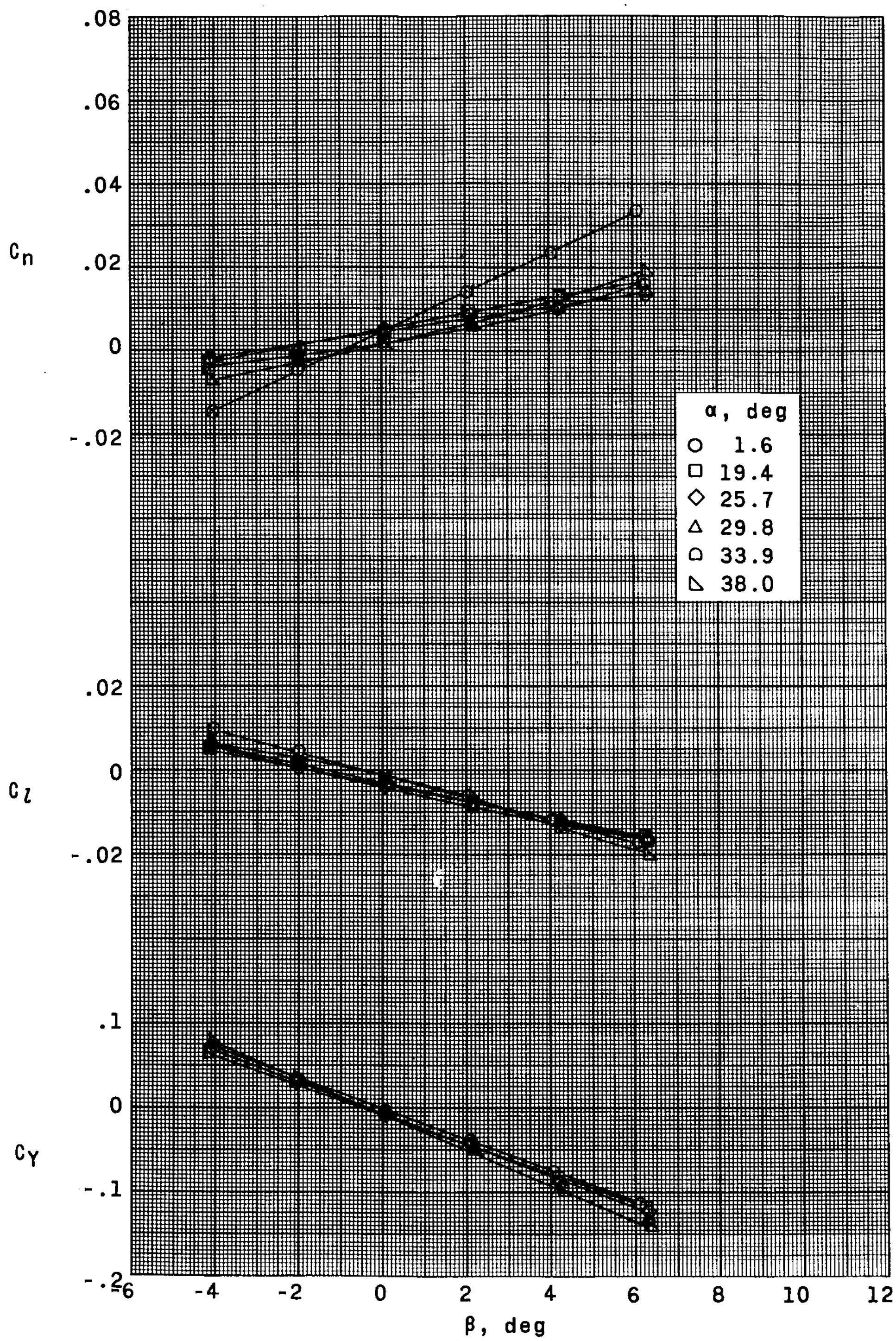
(d) M = 2.86.

Figure 14.- Concluded.



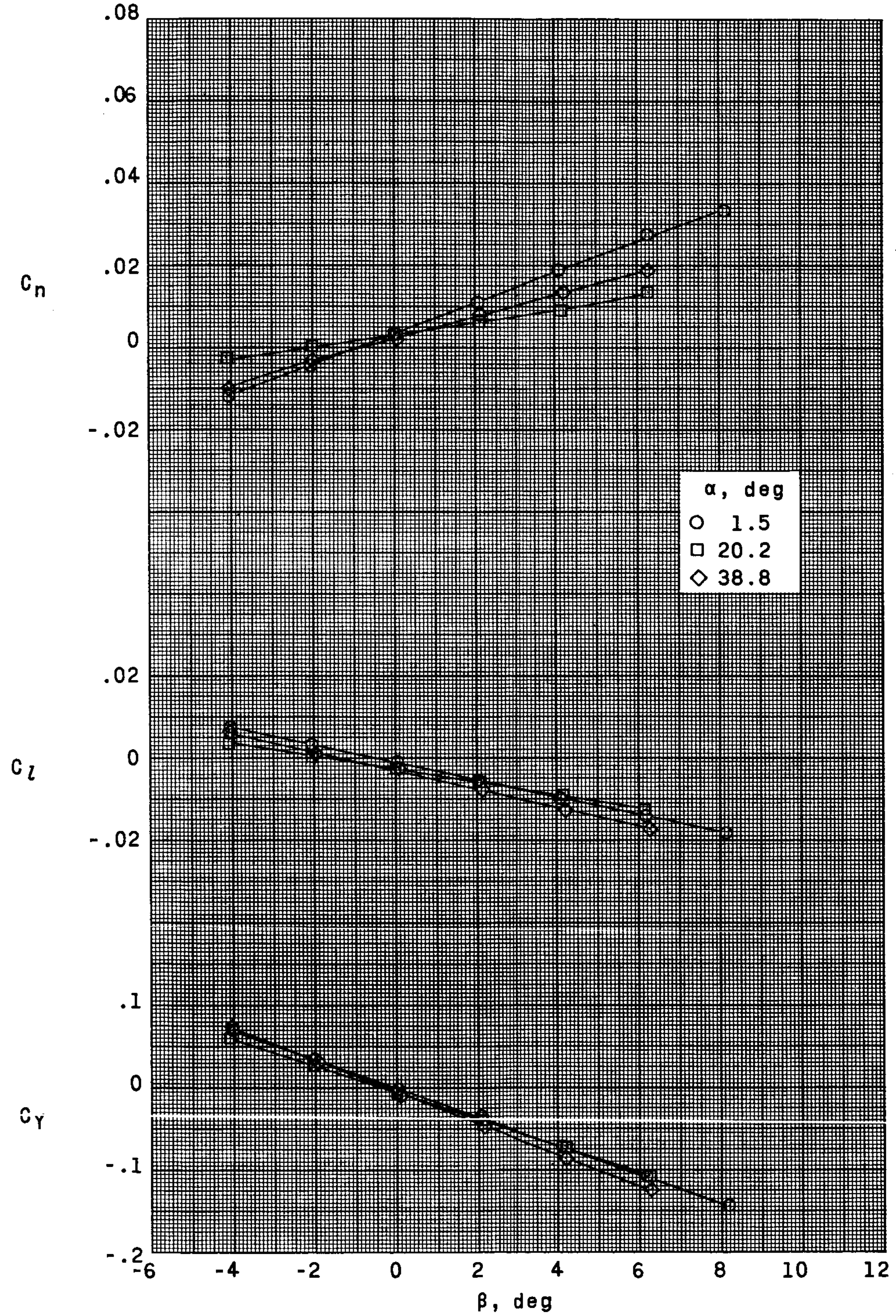
(a) M = 1.50.

Figure 15.- Basic sideslip characteristics of HL-10 with center fin E_2 and tip fins I_2.



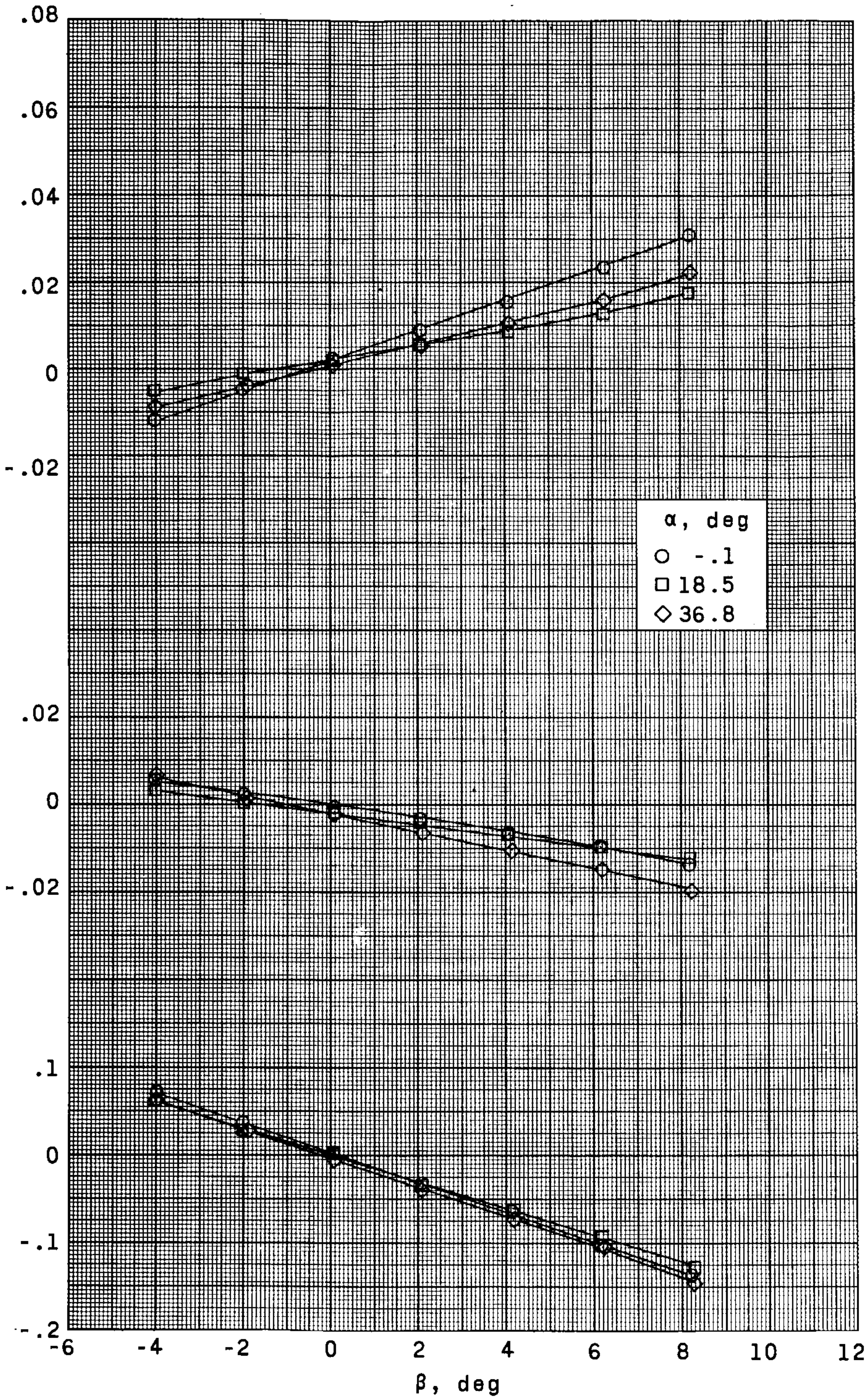
(b) M = 1.80.

Figure 15.- Continued.



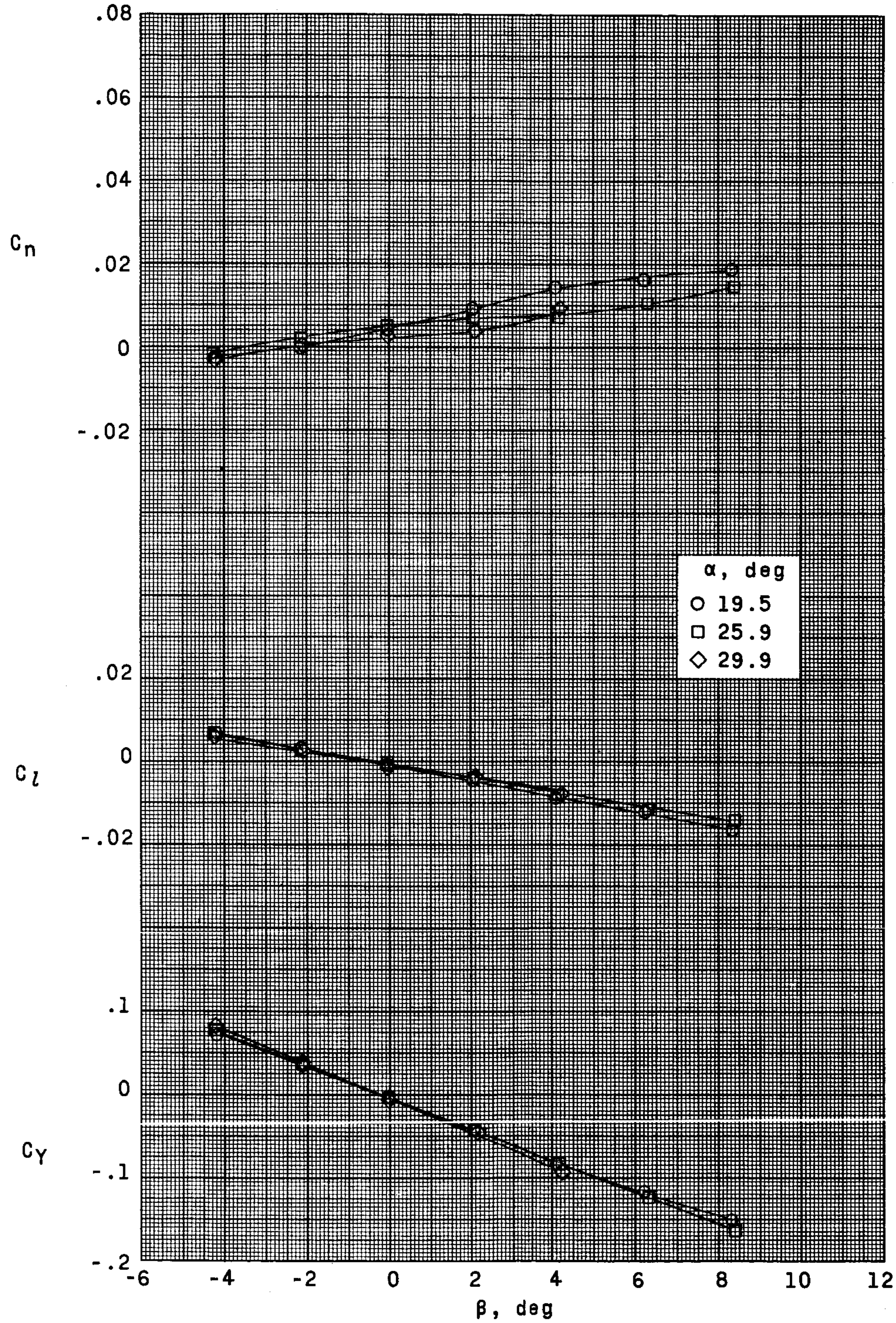
(c) M = 2.16.

Figure 15.- Continued.



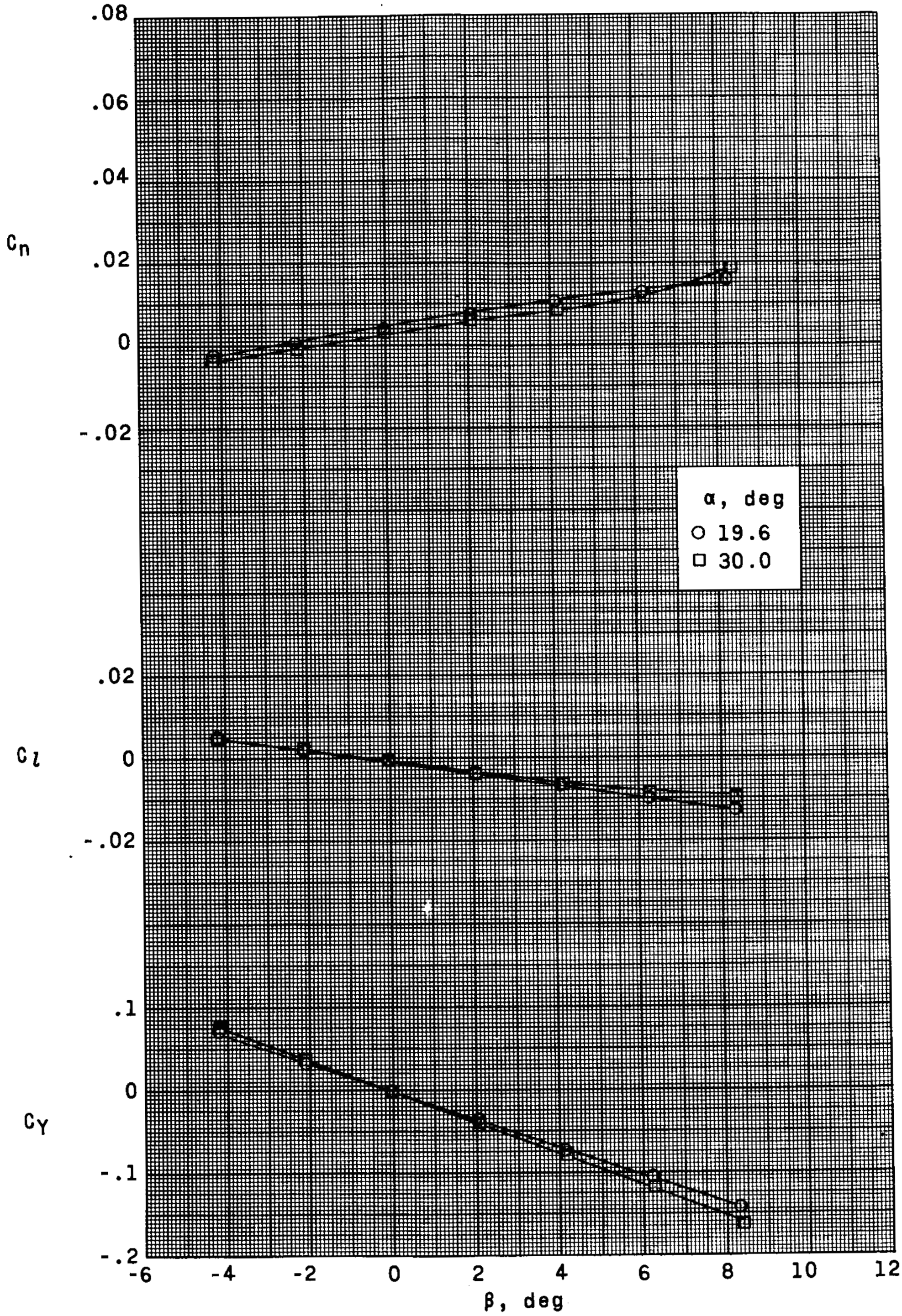
(d) M = 2.86.

Figure 15.- Concluded.



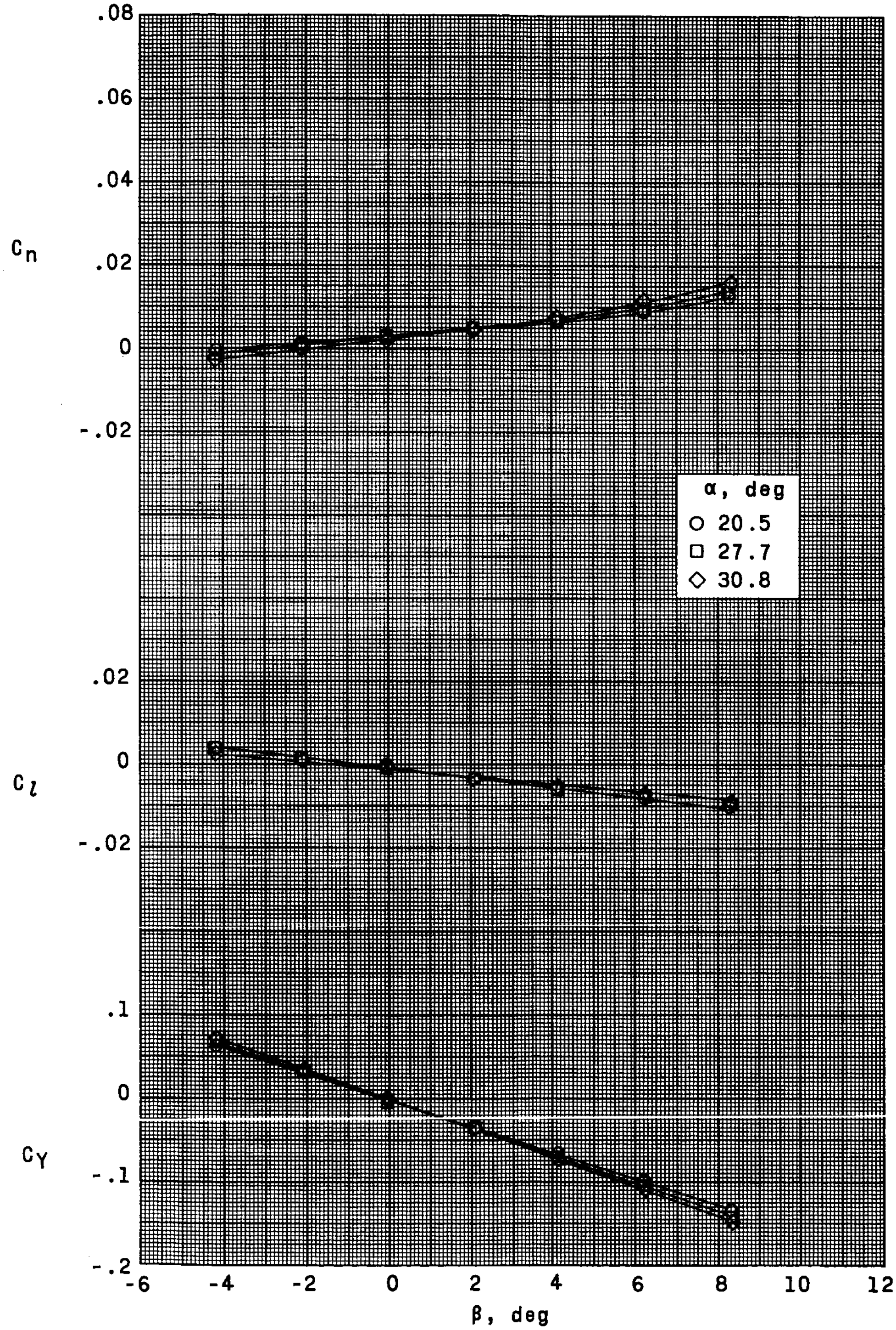
(a) M = 1.50.

Figure 16.- Basic sideslip characteristics of HL-10 with center fin E_2 and tip fins I_3.



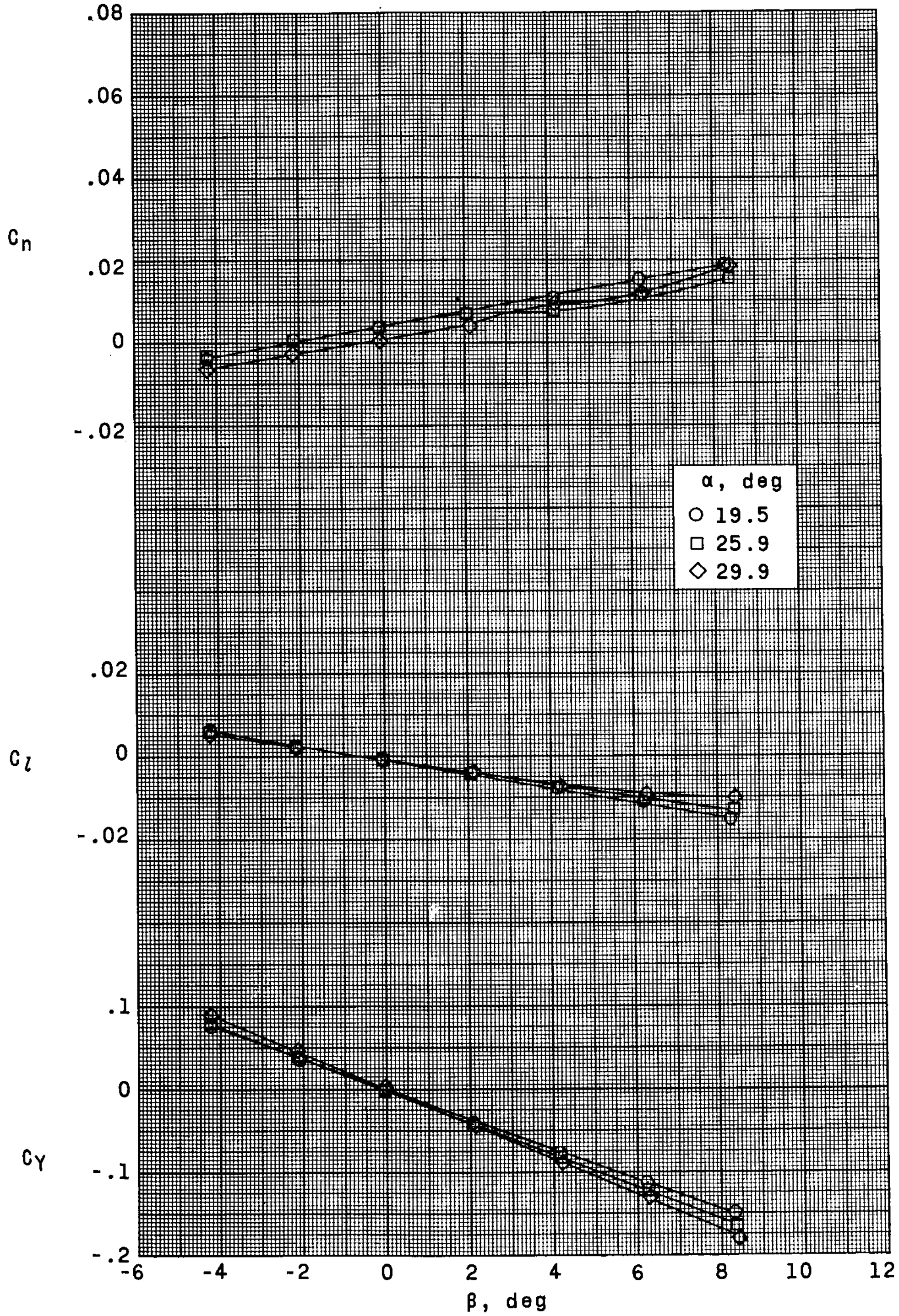
(b) M = 1.80.

Figure 16.- Continued.



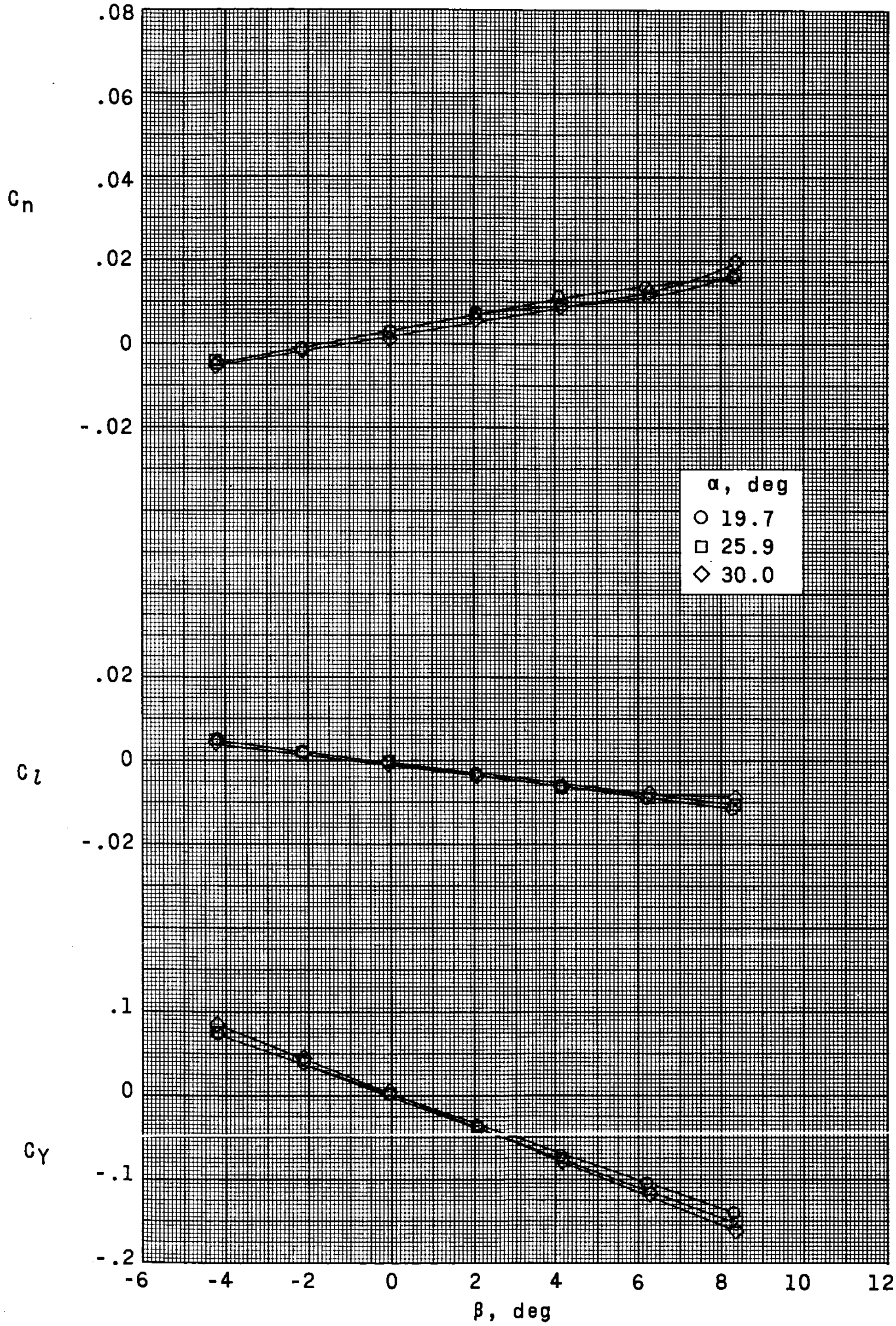
(c) M = 2.16.

Figure 16.- Concluded.



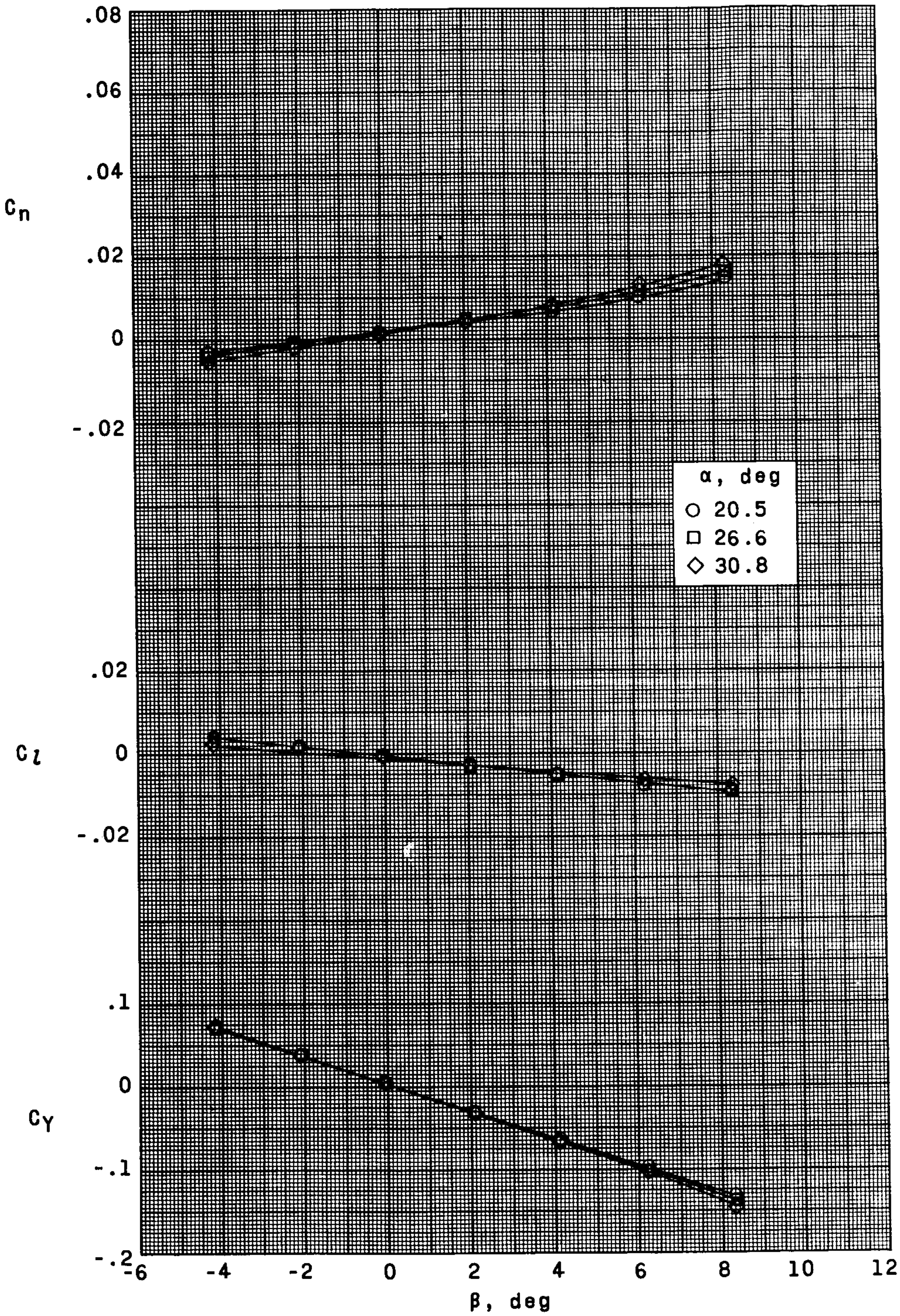
(a) M = 1.50.

Figure 17.- Basic sideslip characteristics of HL-10 with center fin E_2 and tip fins I_4.



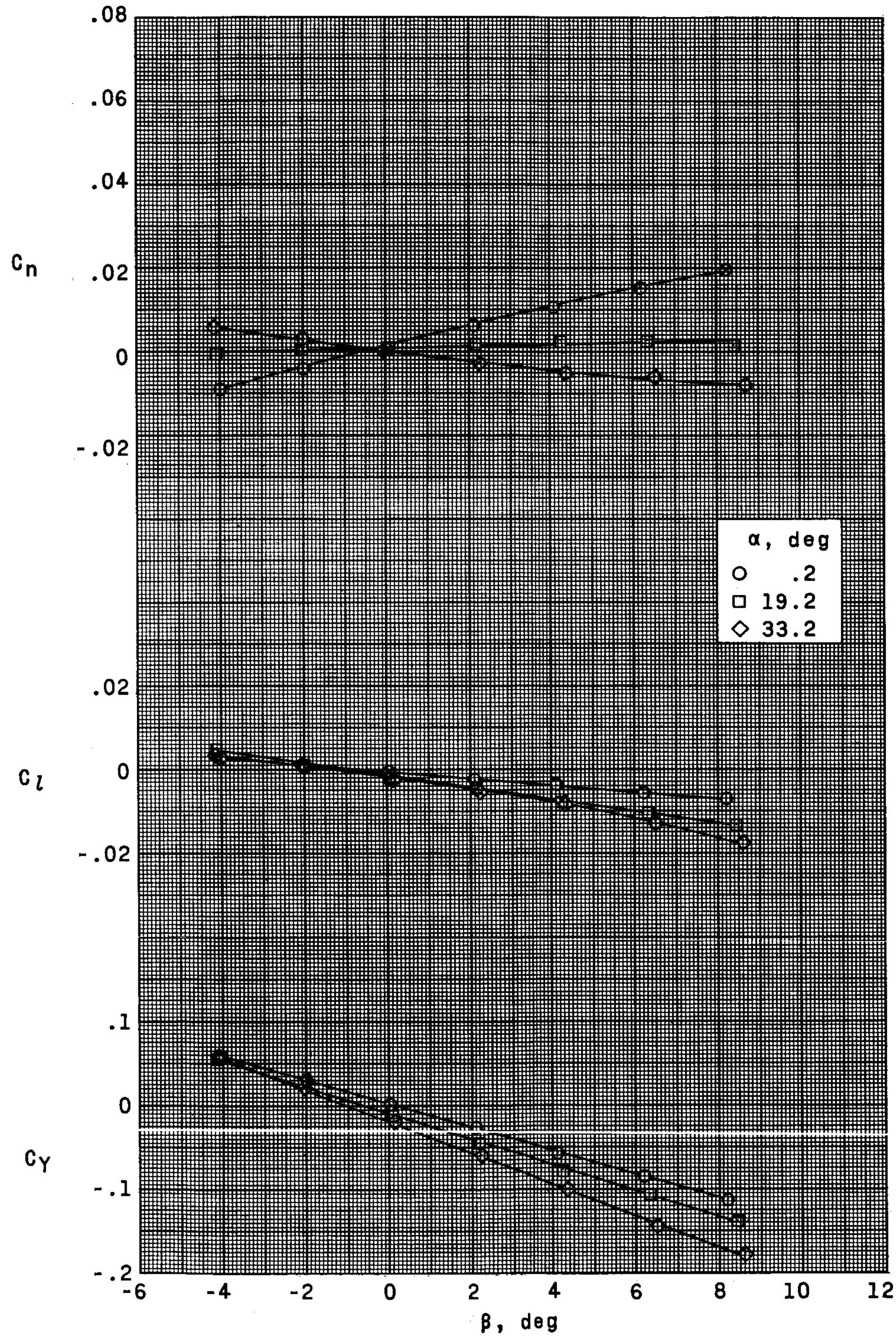
(b) M = 1.80.

Figure 17.- Continued.



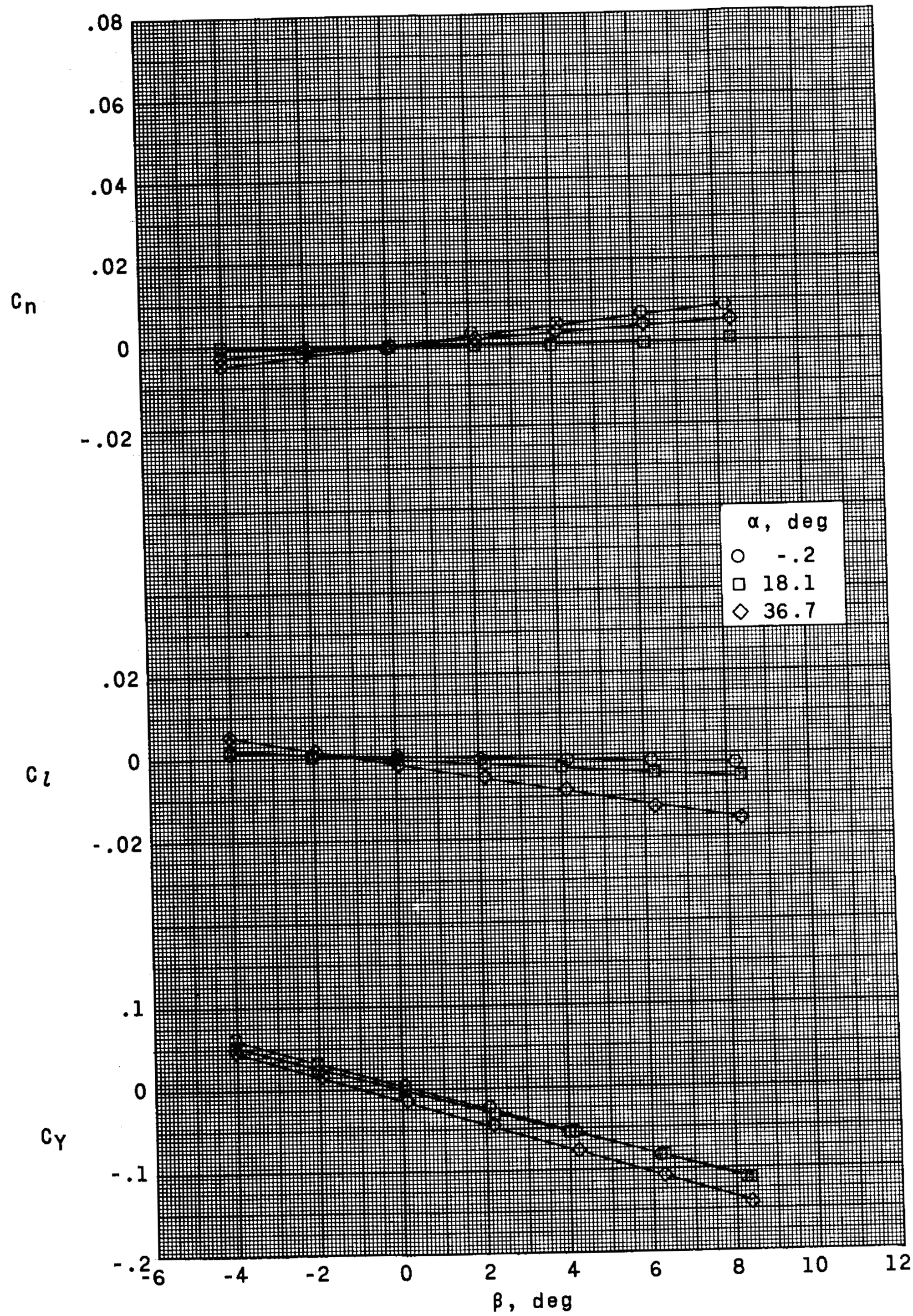
(c) M = 2.16.

Figure 17.- Concluded.



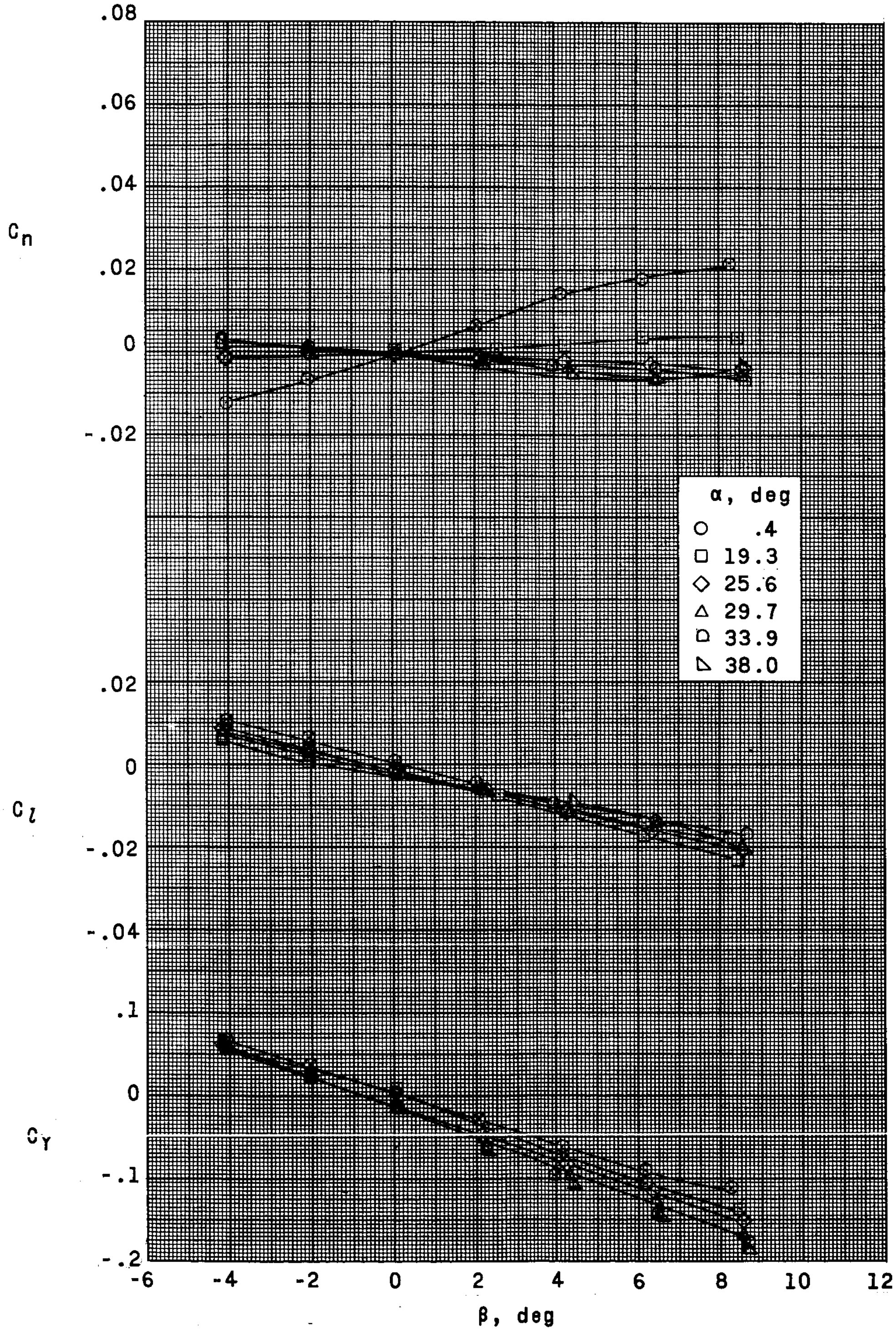
(a) M = 1.50.

Figure 18.- Basic sideslip characteristics of HL-11 with center fin E and tip fins D-1; $\delta_e = 0^o$.



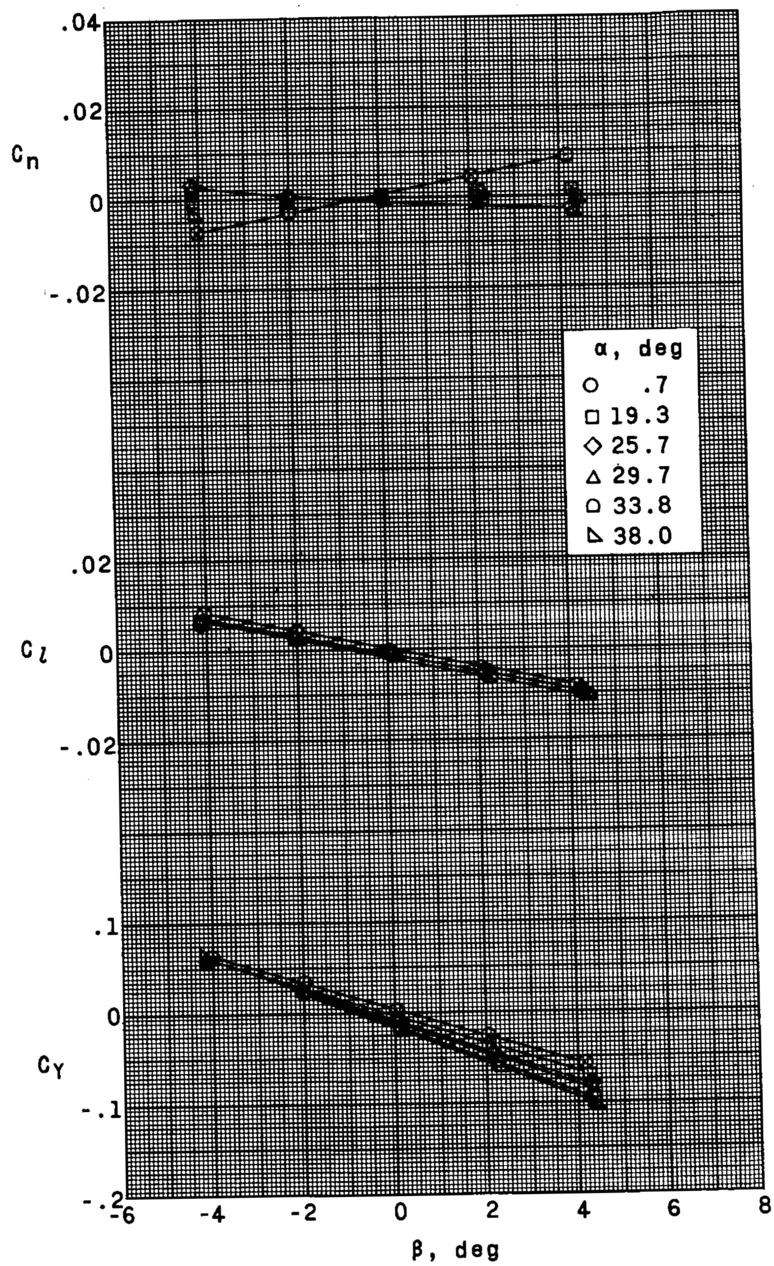
(b) M = 2.86.

Figure 18.- Concluded.



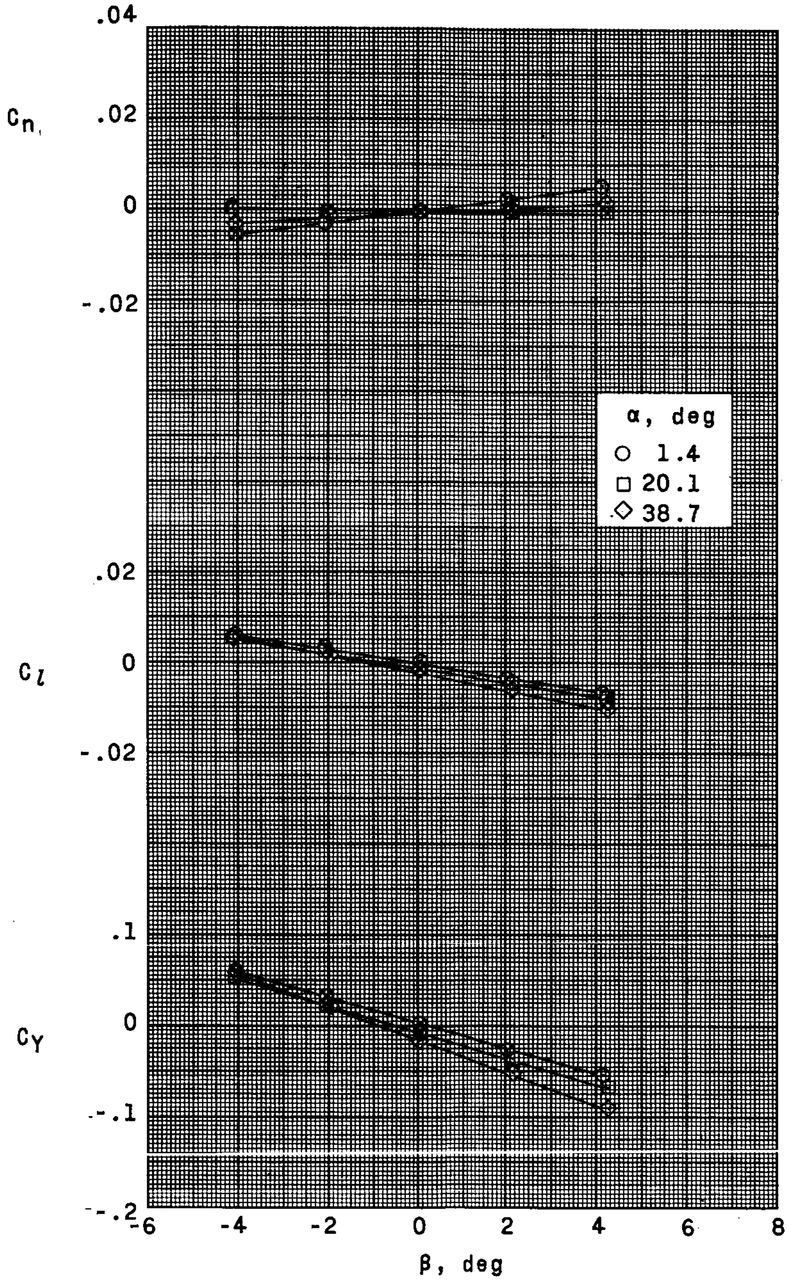
(a) M = 1.50.

Figure 19.- Basic sideslip characteristics of HL-11 with center fin E and tip fins D-1; $\delta_e = -30^{\circ}$.



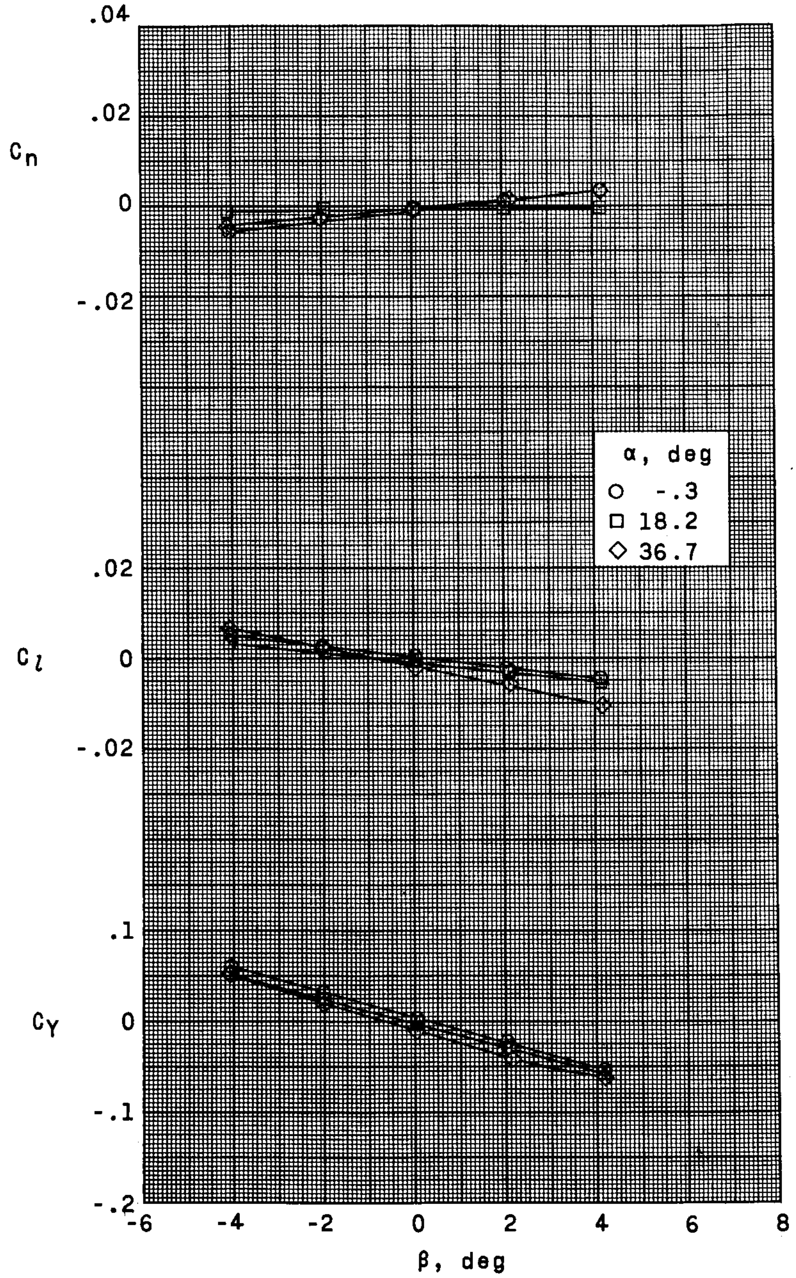
(b) M = 1.80.

Figure 19.- Continued.



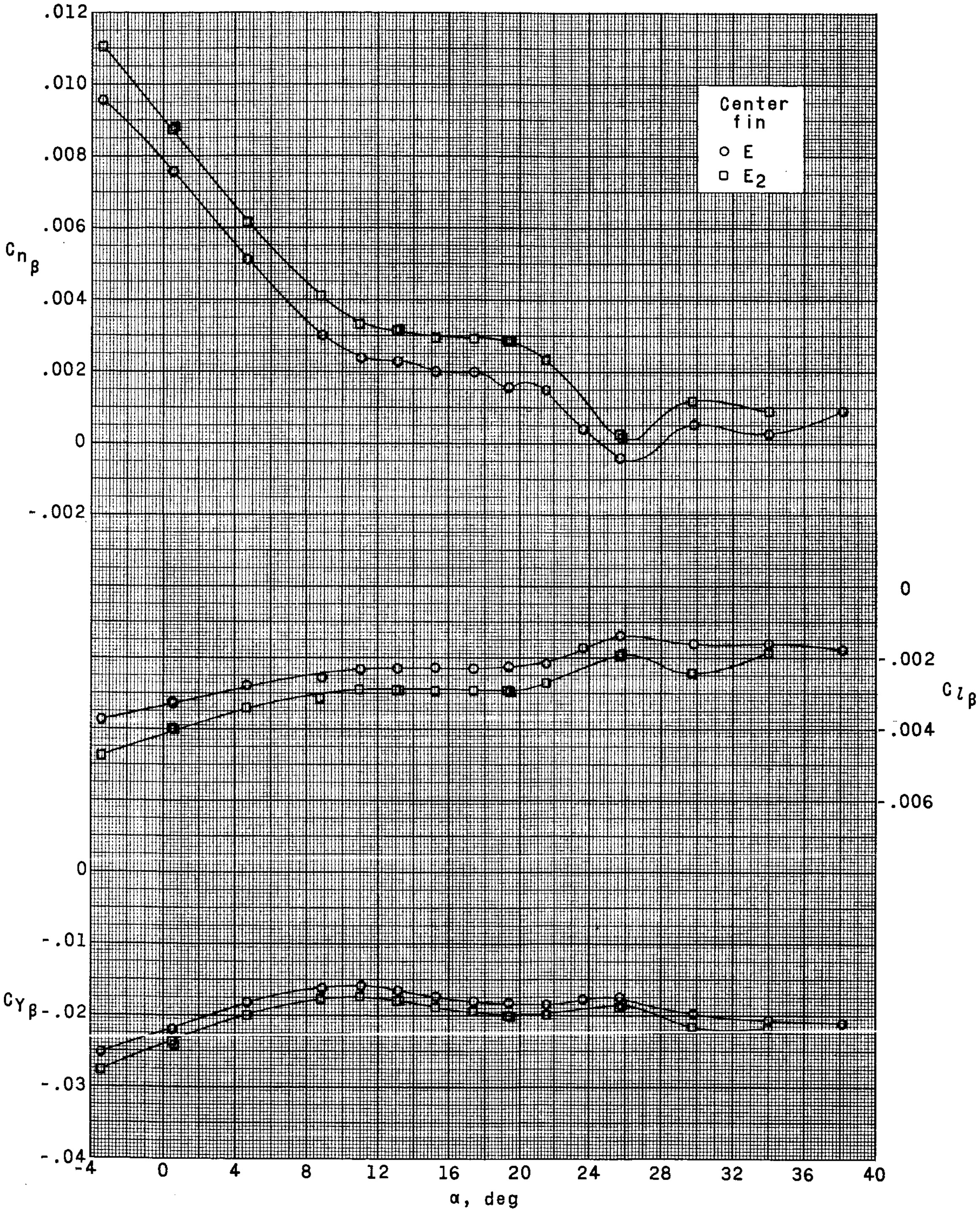
(c) M = 2.16.

Figure 19.- Continued.



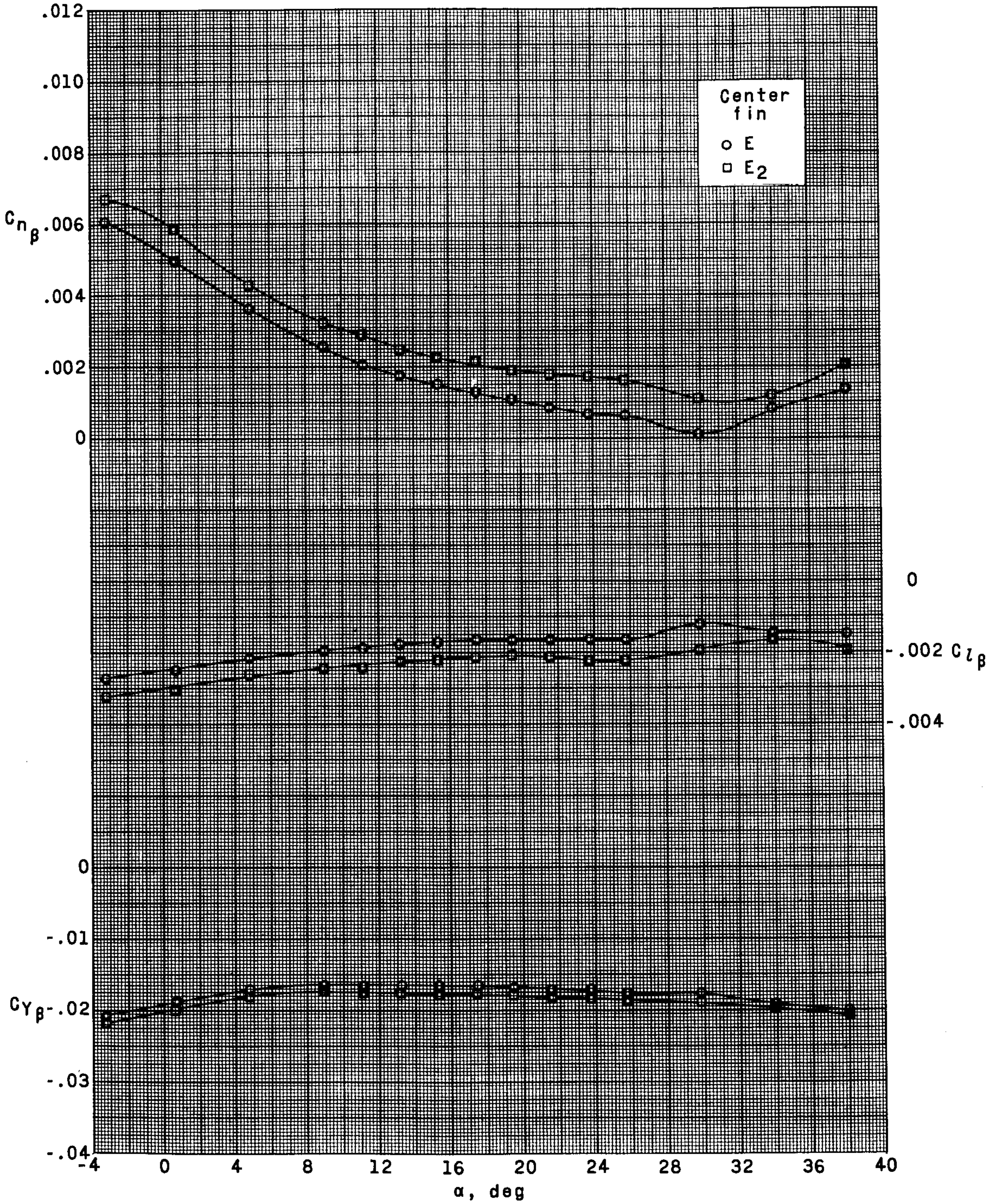
(d) M = 2.86.

Figure 19.- Concluded.



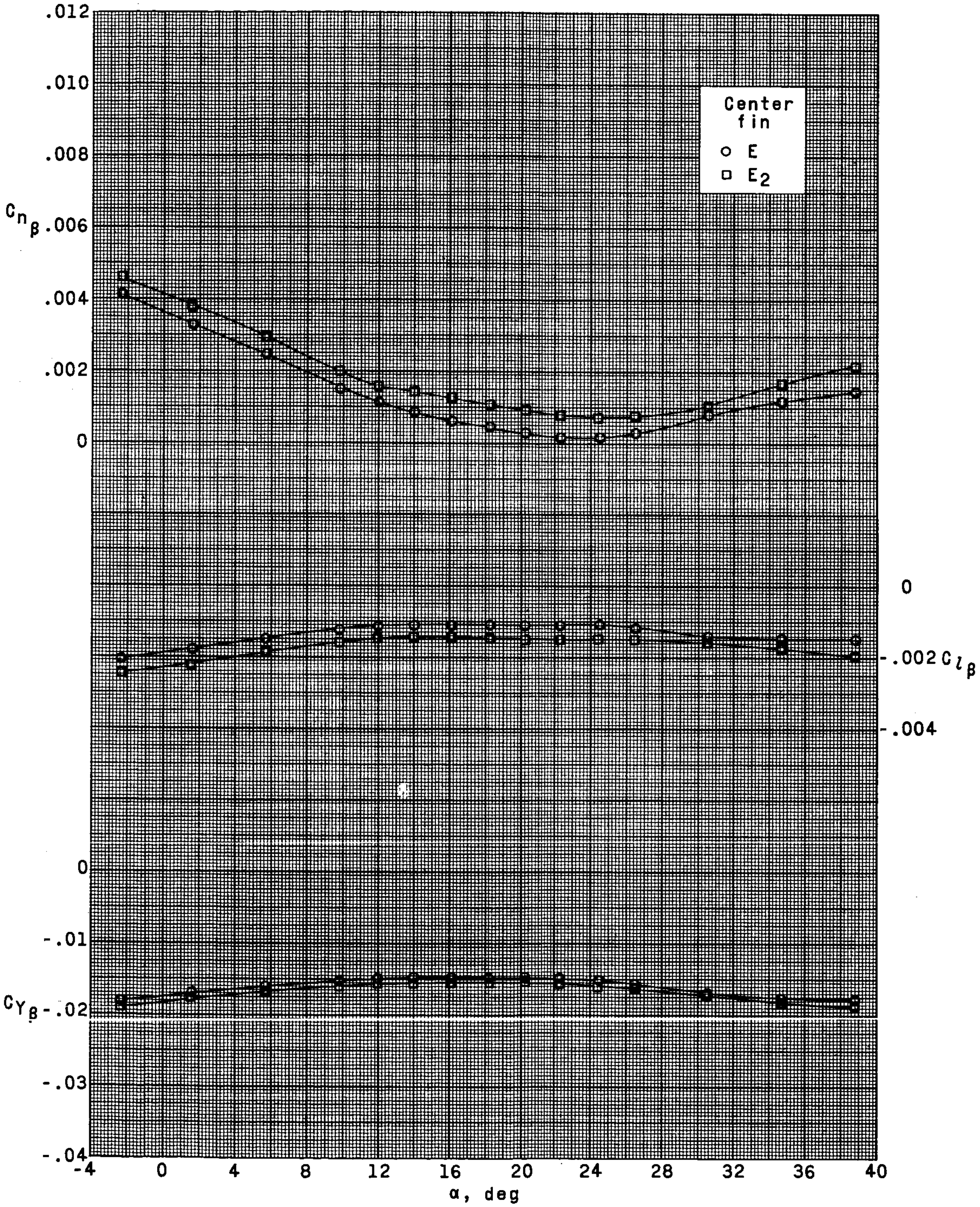
(a) M = 1.50.

Figure 20.- Effects of center fins E and E_2 on lateral and directional stability derivatives of HL-10 with tip fins P_1.



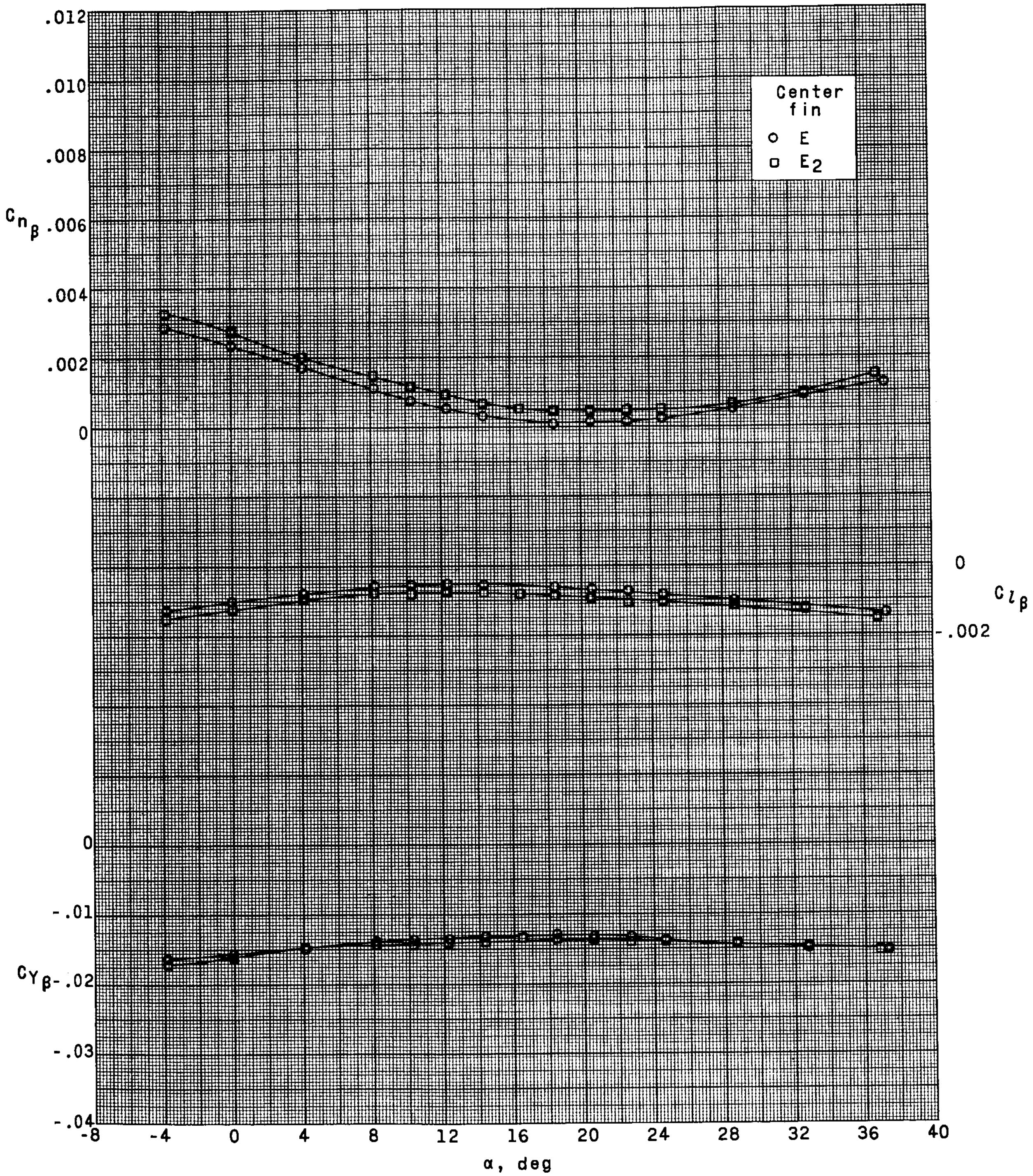
(b) M = 1.80.

Figure 20.- Continued.



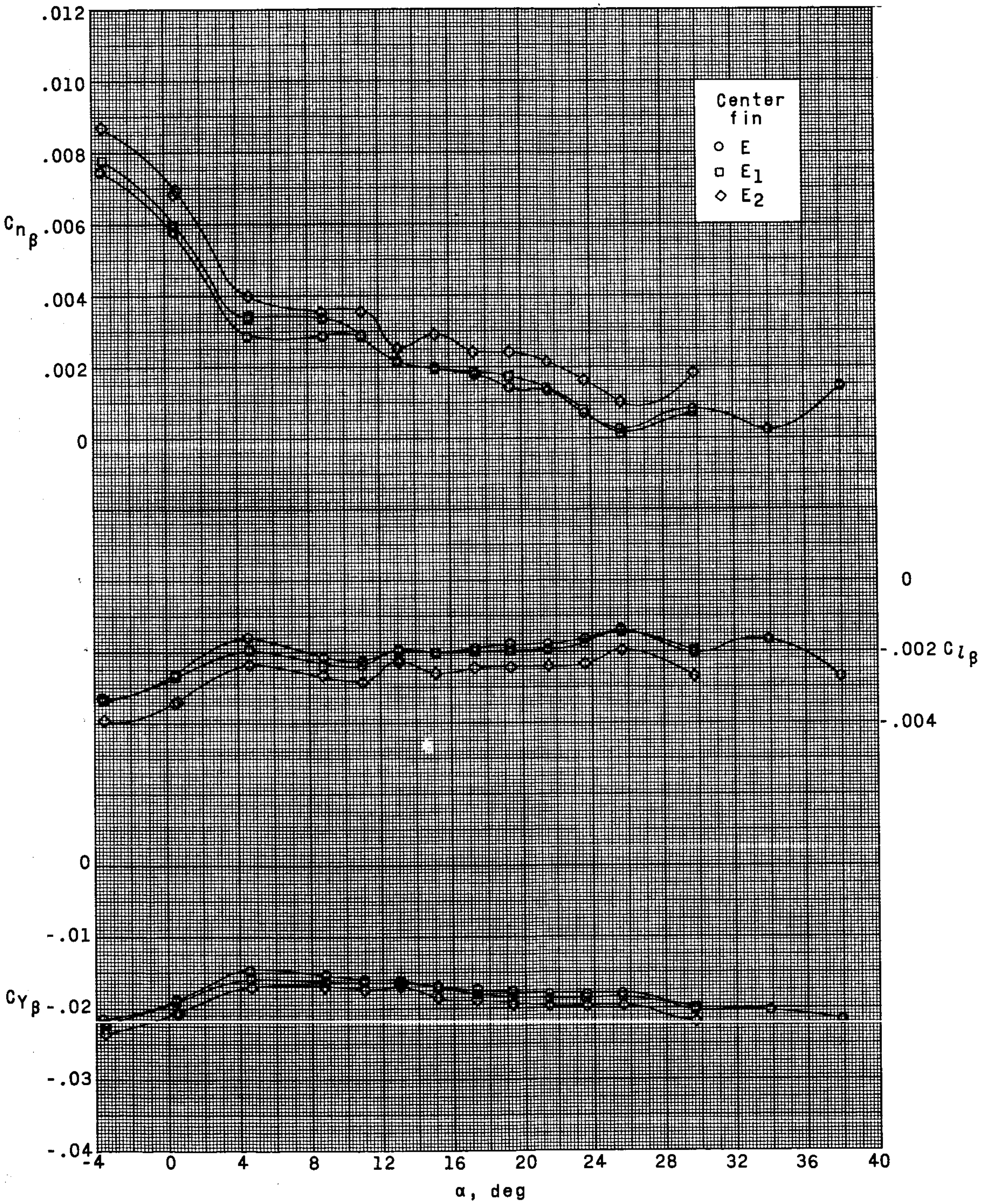
(c) M = 2.16.

Figure 20.- Continued.



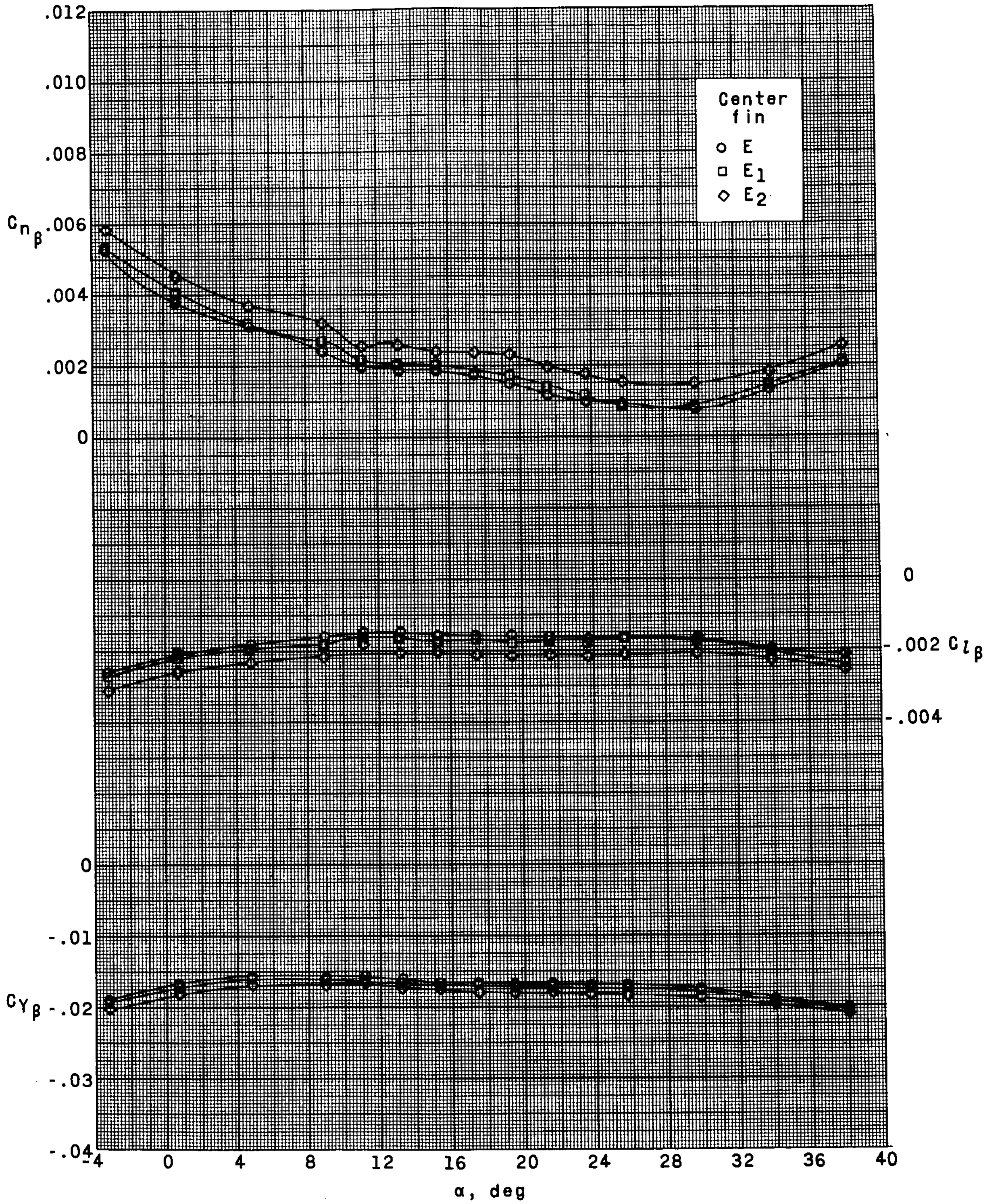
(d) M = 2.86.

Figure 20.- Concluded.



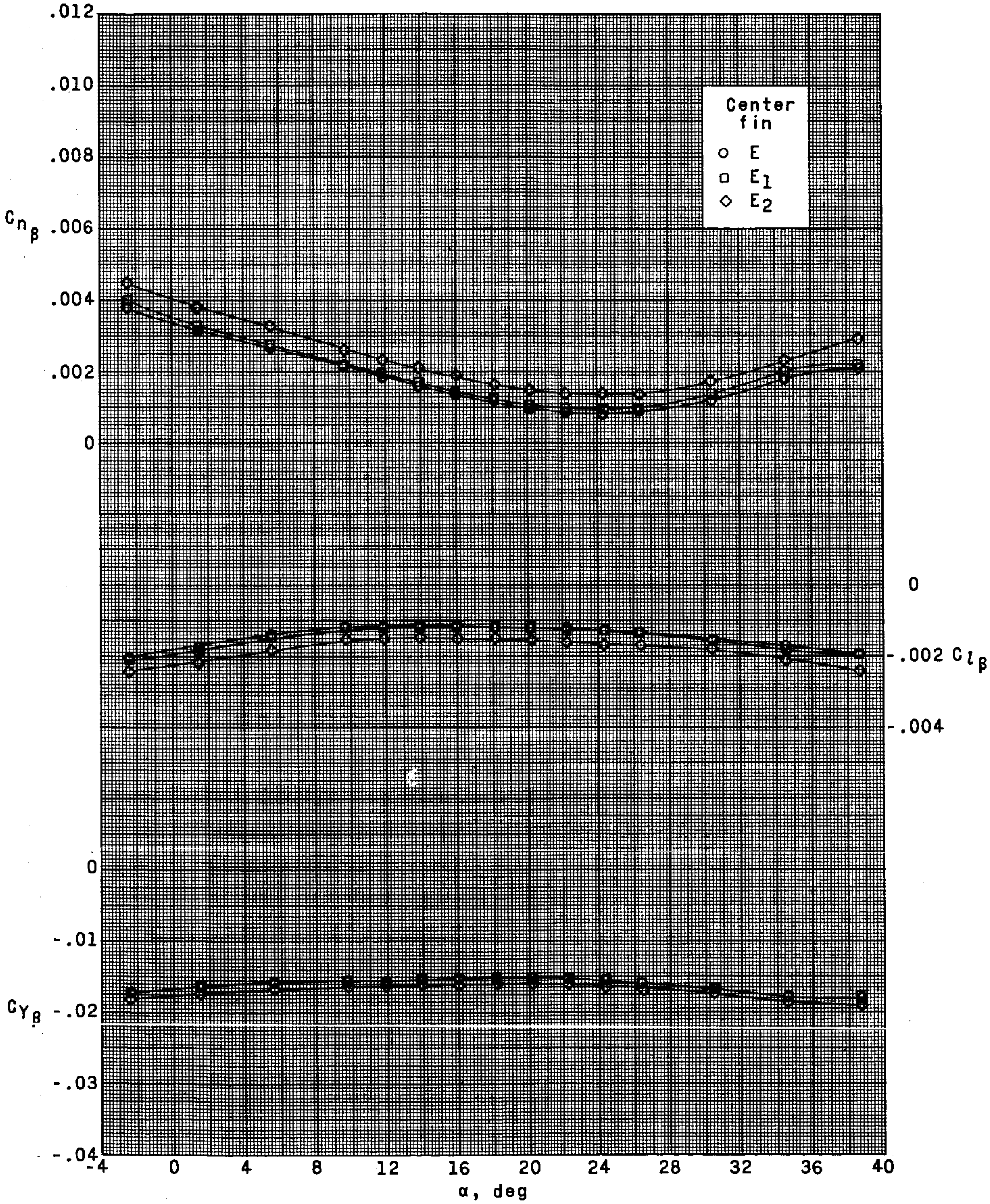
(a) $M = 1.50$.

Figure 21.- Effects of center fins E, E_1, and E_2 on lateral and directional stability derivatives of HL-10 with tip fins I_2.



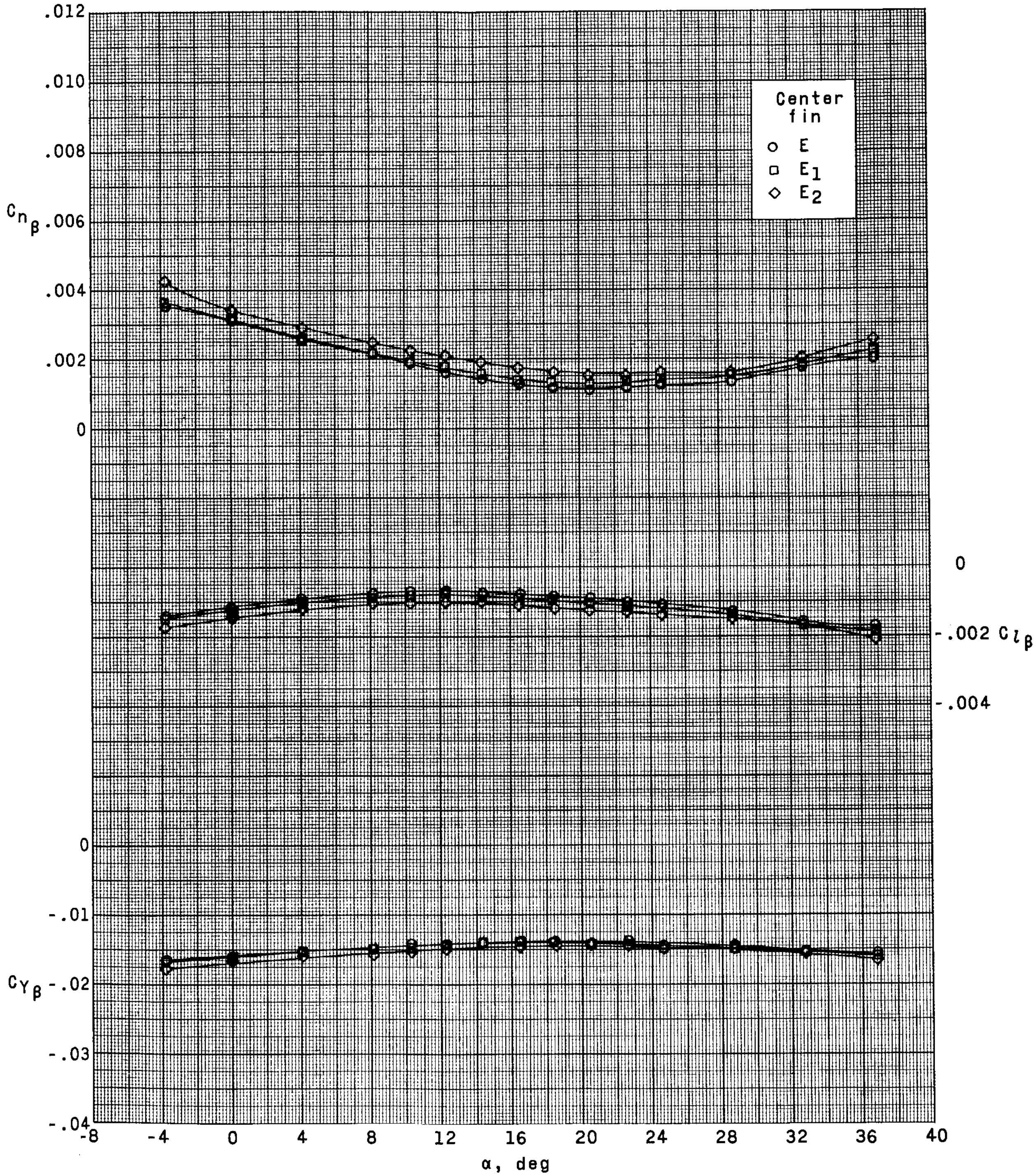
(b) M = 1.80.

Figure 21.- Continued.



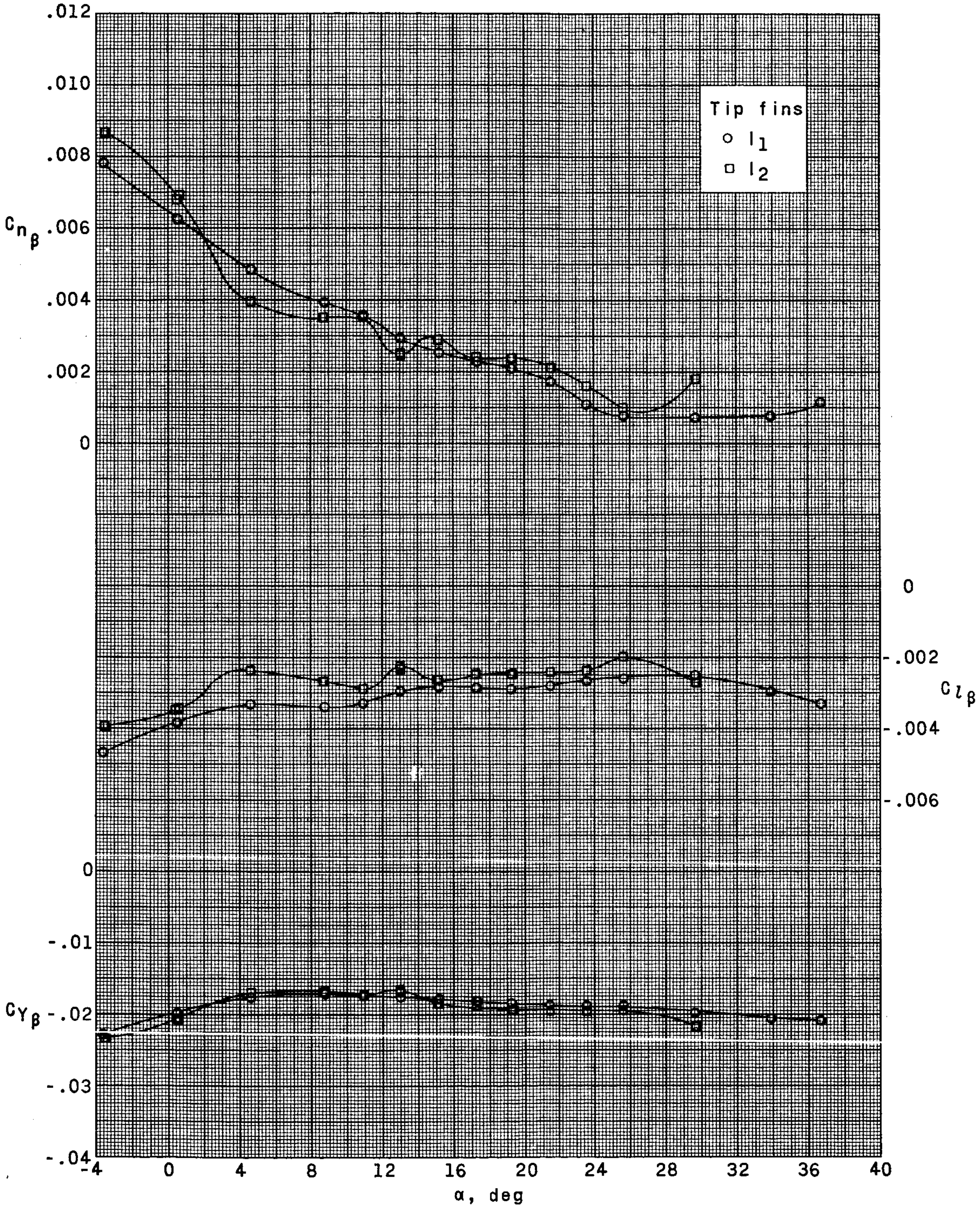
(c) M = 2.16.

Figure 21.- Continued.



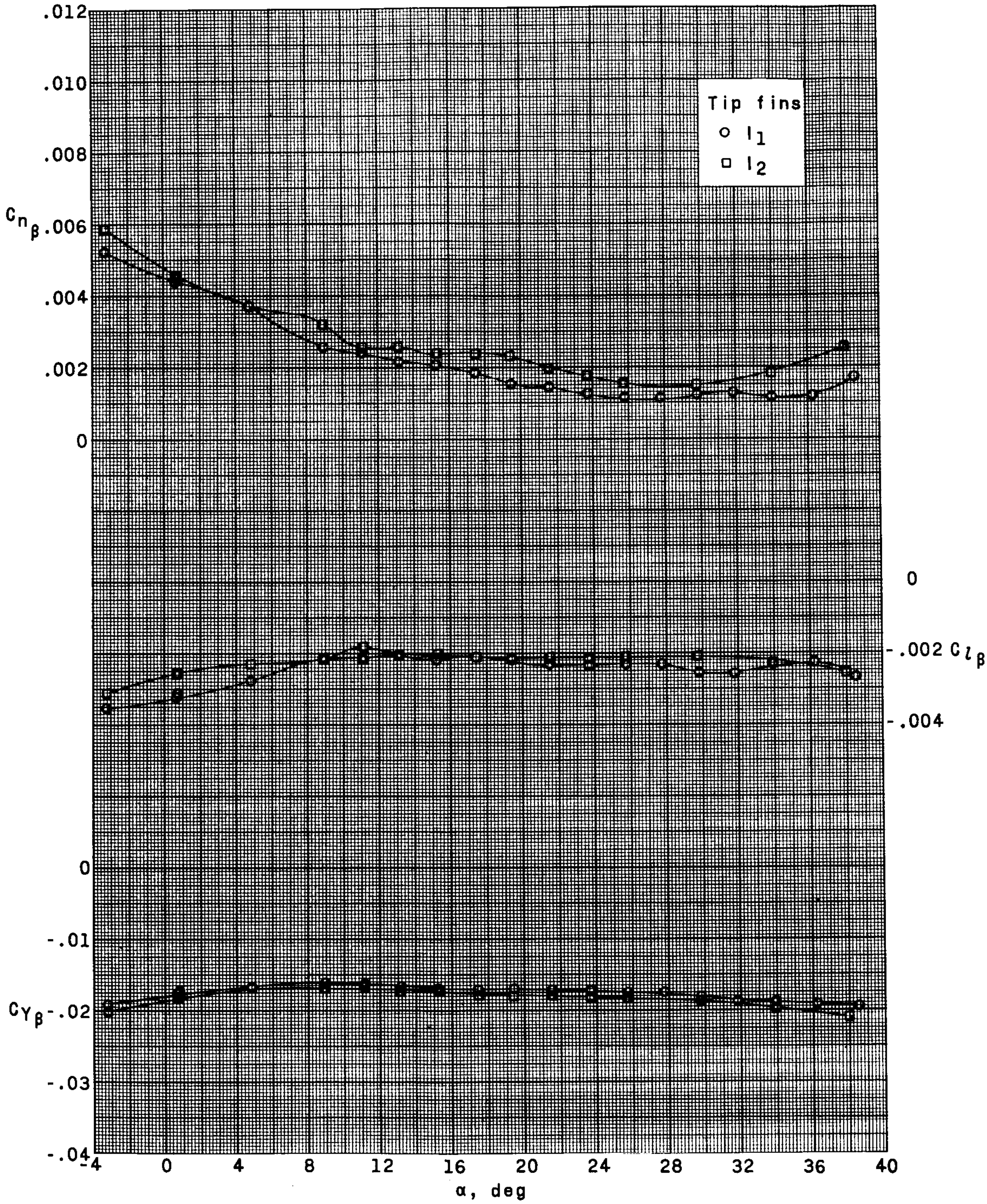
(d) M = 2.86.

Figure 21.- Concluded.



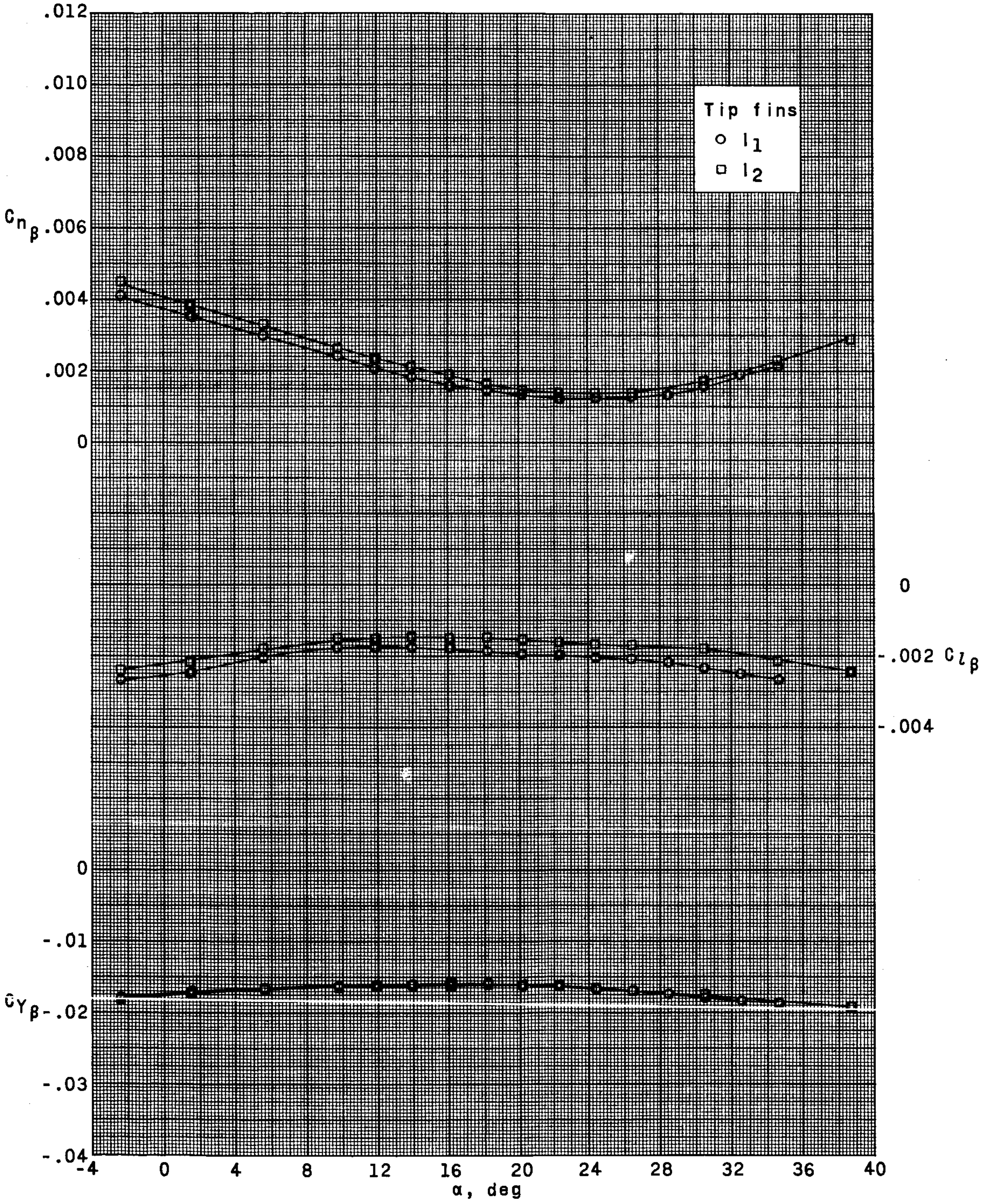
(a) M = 1.50.

Figure 22.- Effects of tip fins I_1 and I_2 on lateral and directional stability derivatives of HL-10 with center fin E_2.



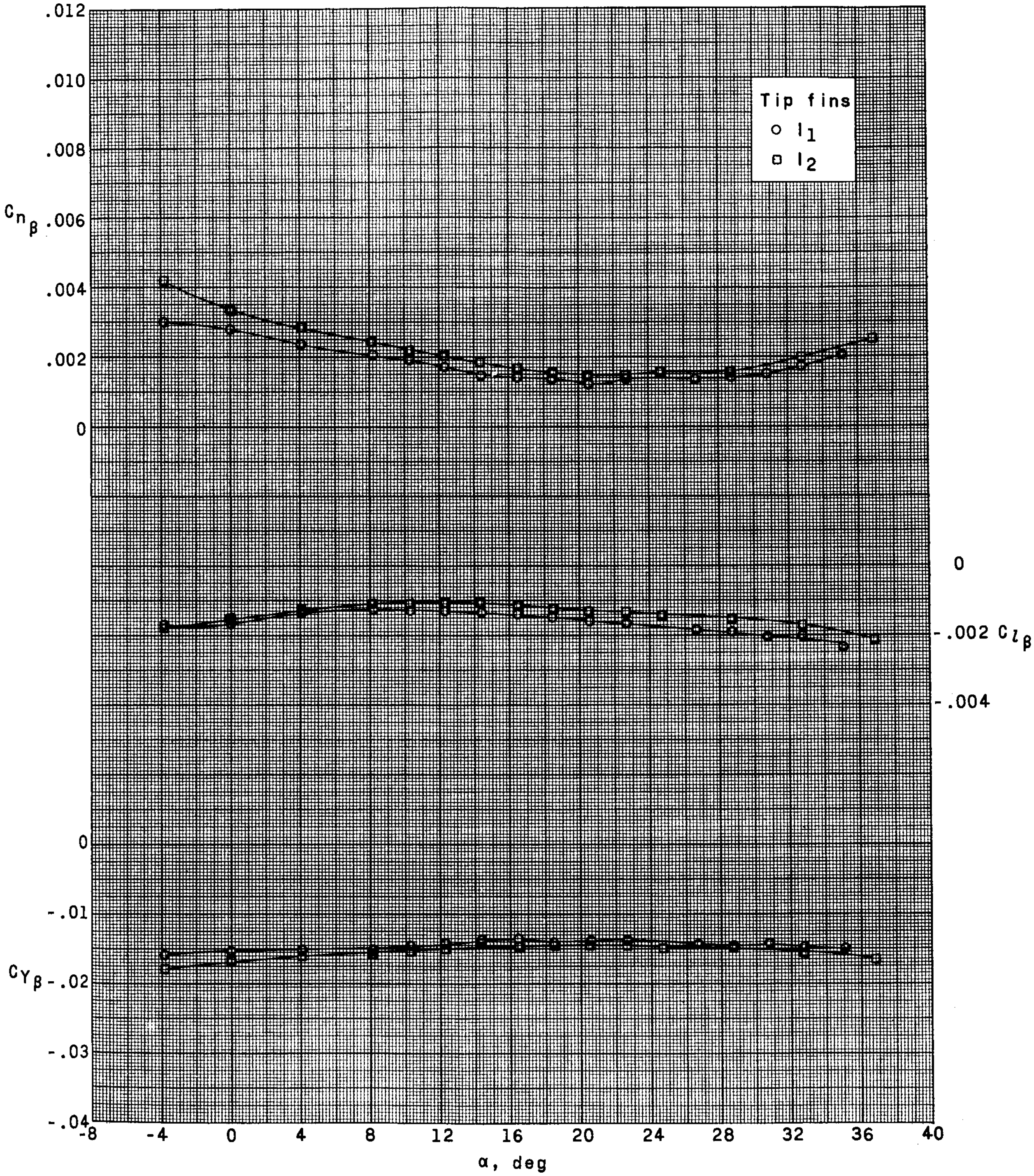
(b) M = 1.80.

Figure 22.- Continued.



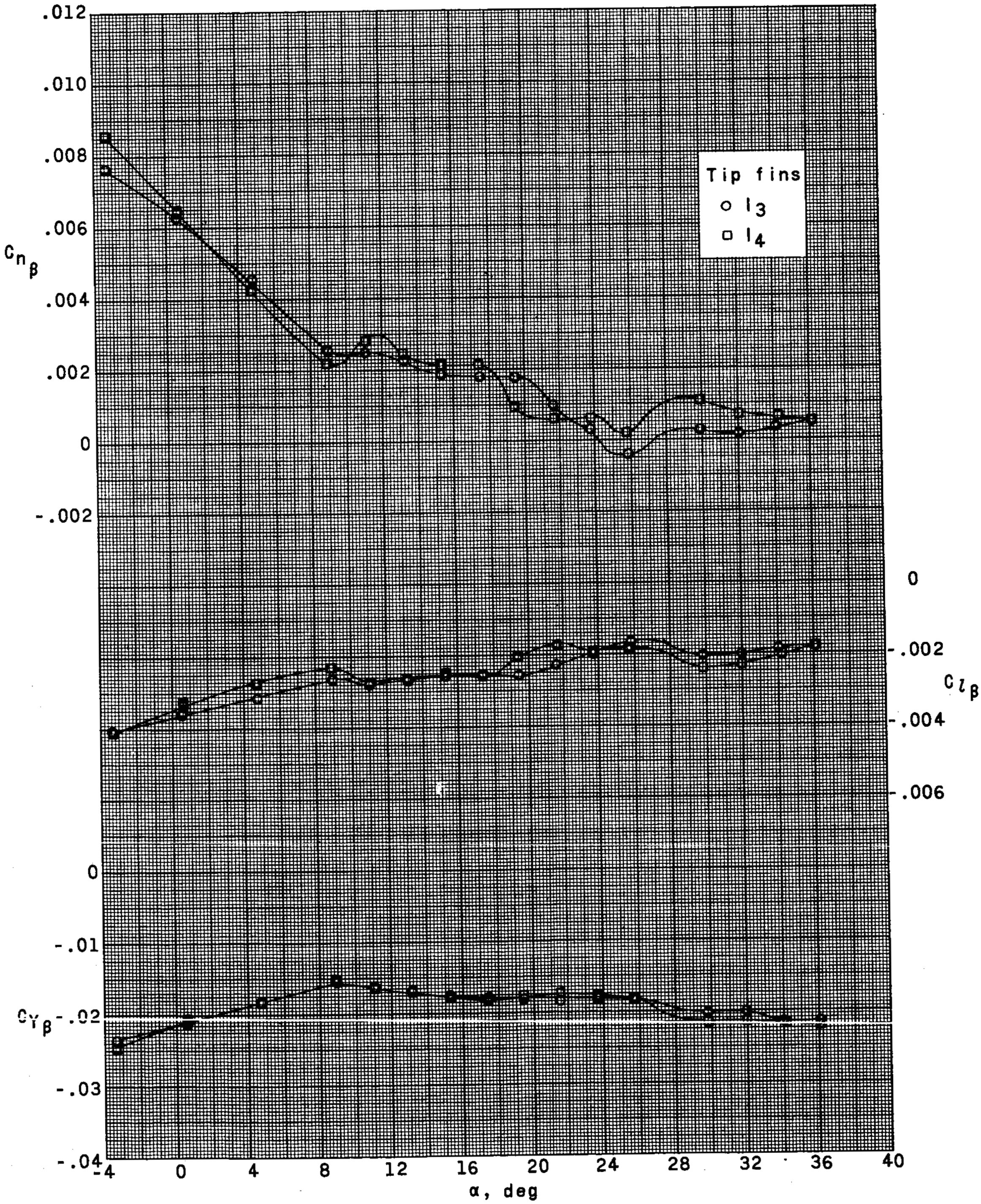
(c) M = 2.16.

Figure 22.- Continued.



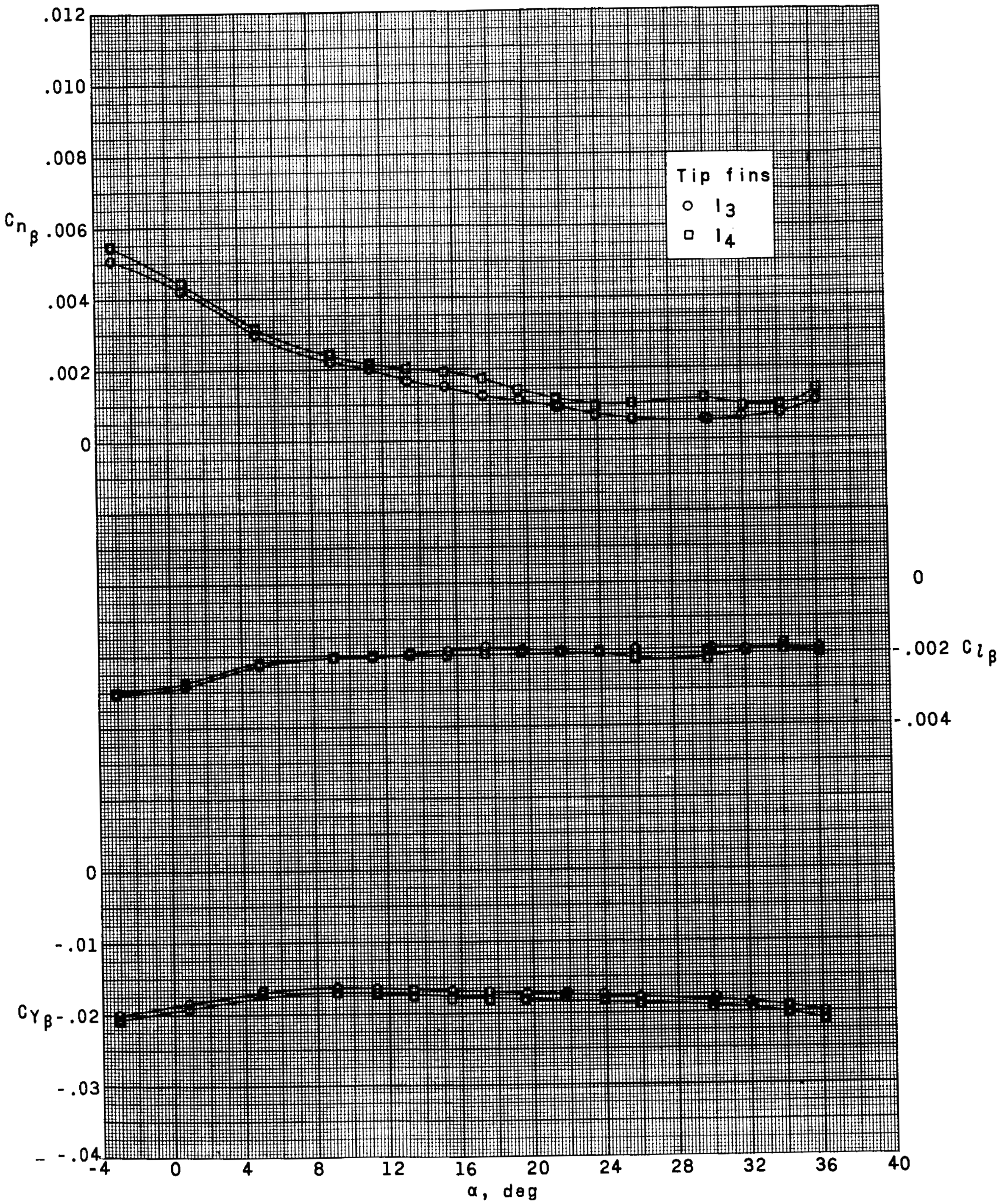
(d) M = 2.86.

Figure 22.- Concluded.



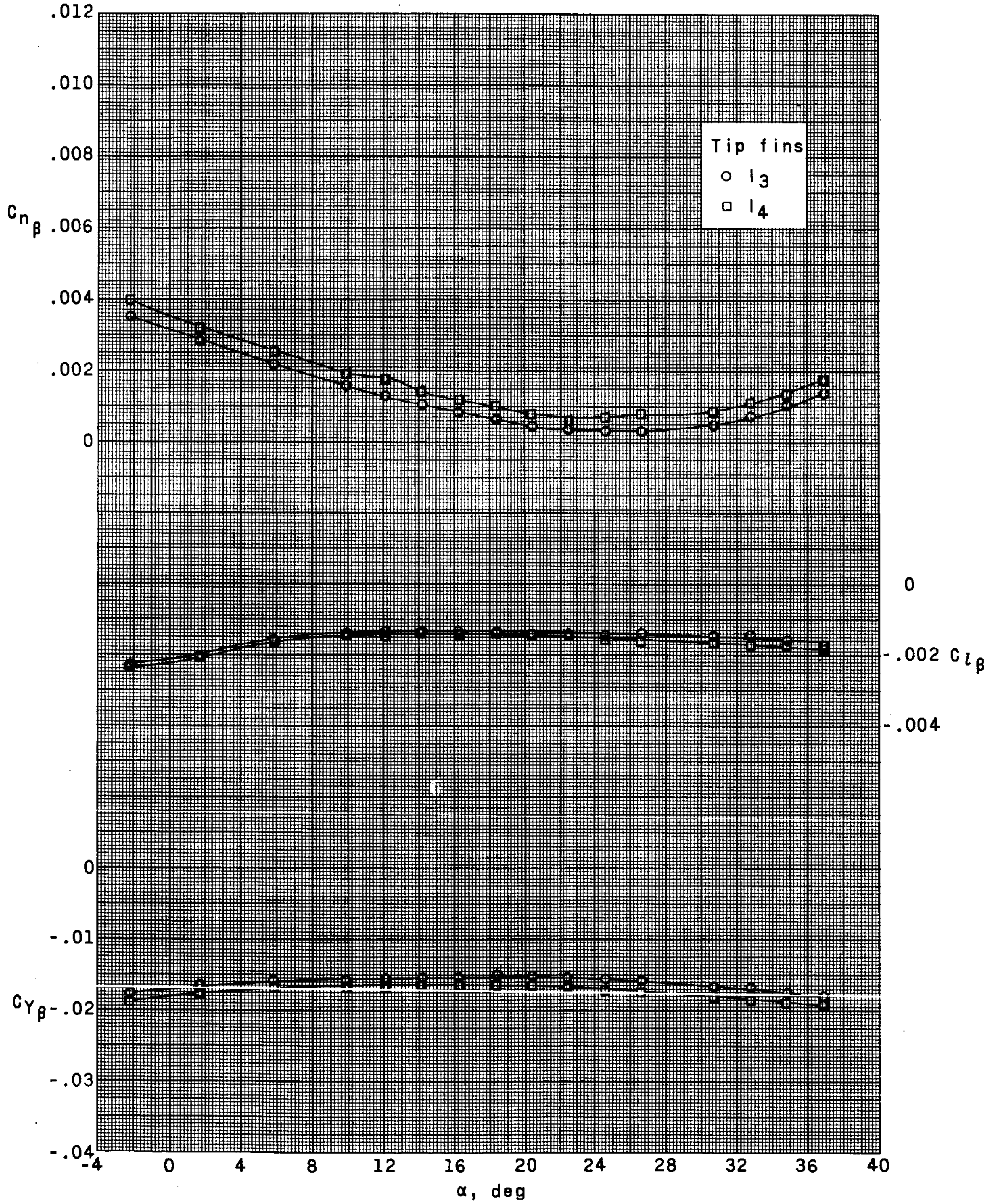
(a) M = 1.50.

Figure 23.- Effects of tip fins l_3 and l_4 on lateral and directional stability derivatives of HL-10 with center fin E_2.



(b) M = 1.80.

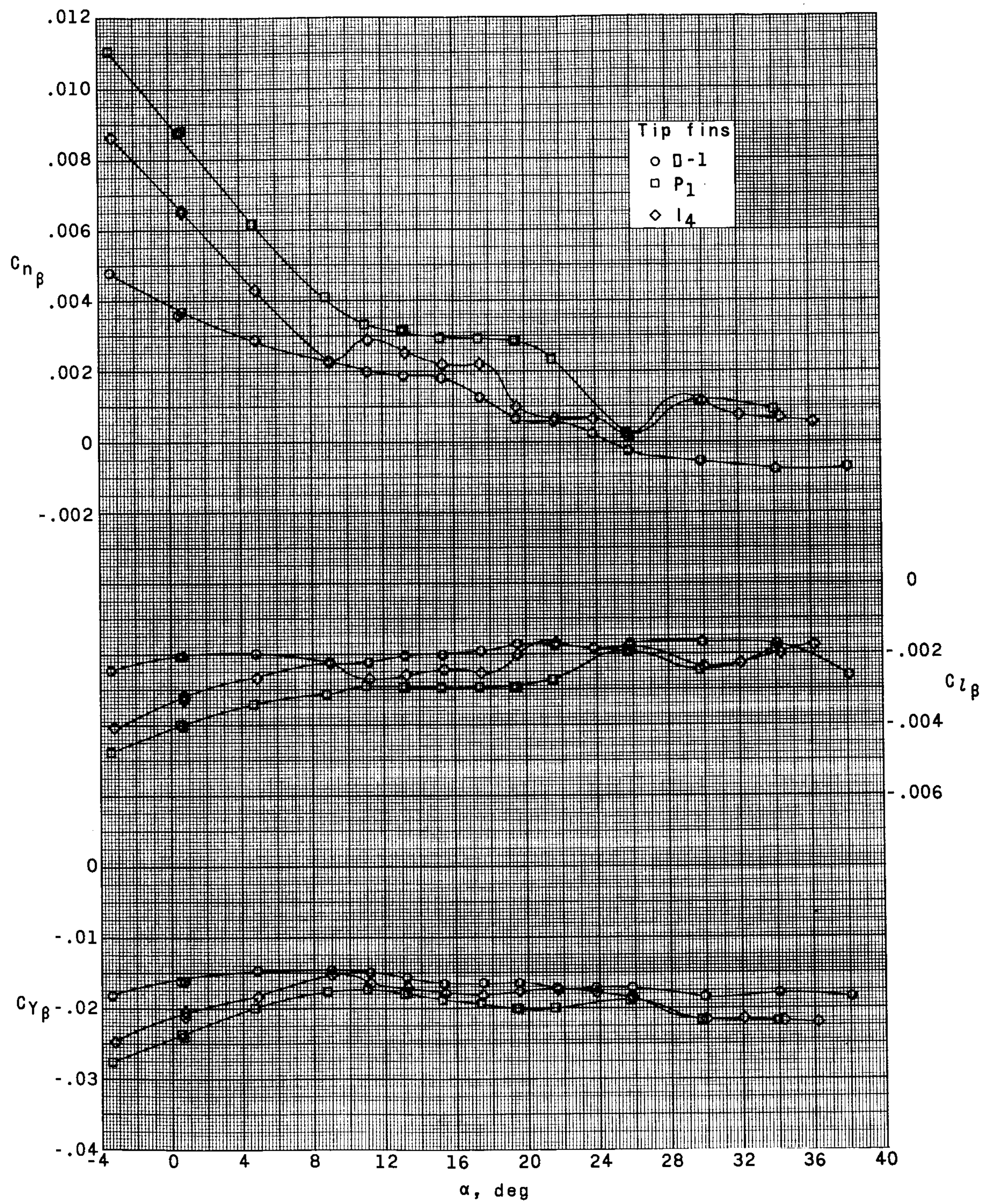
Figure 23.- Continued.



(c) M = 2.16.

Figure 23.- Concluded.

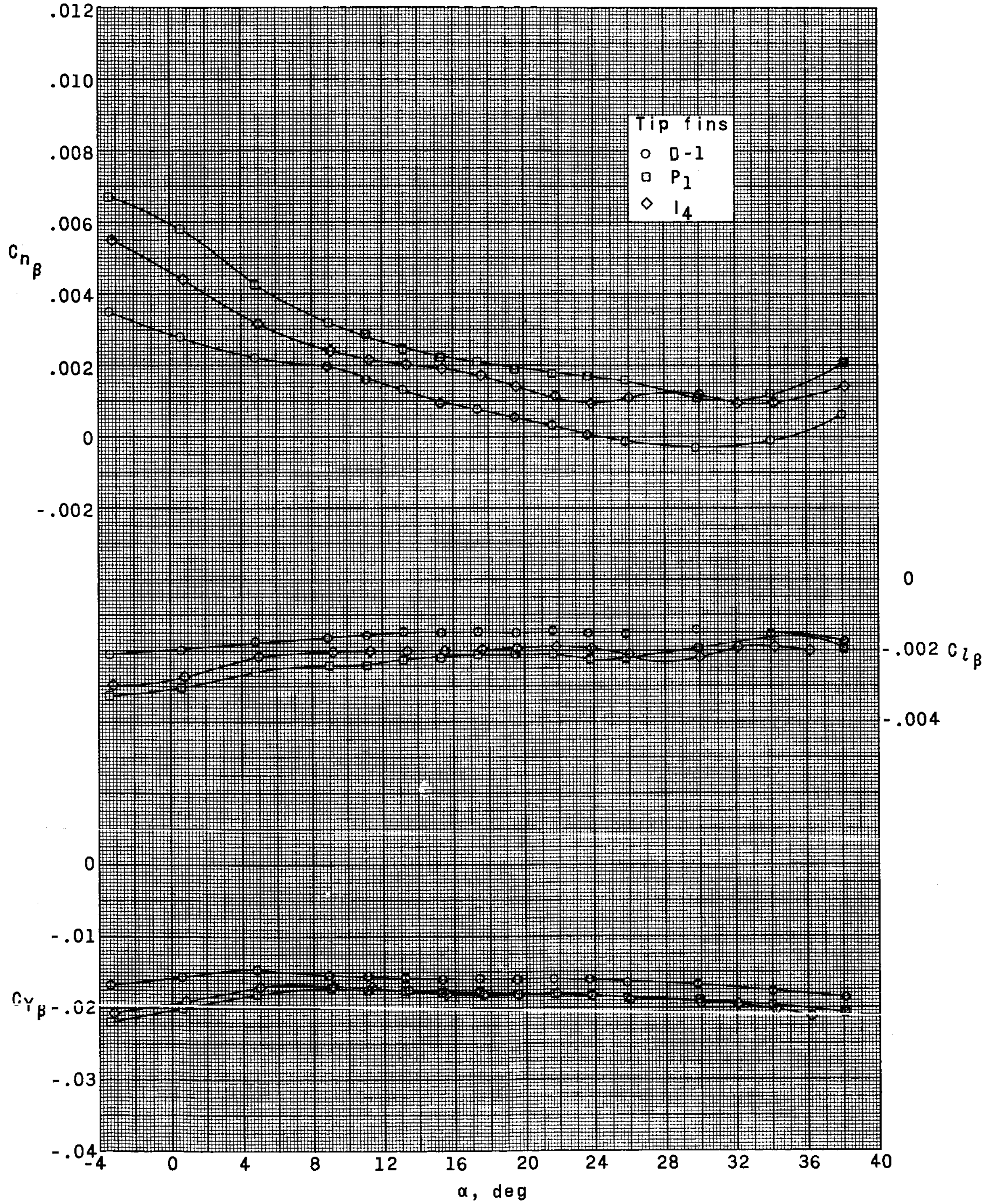
[redacted]



(a) M = 1.50.

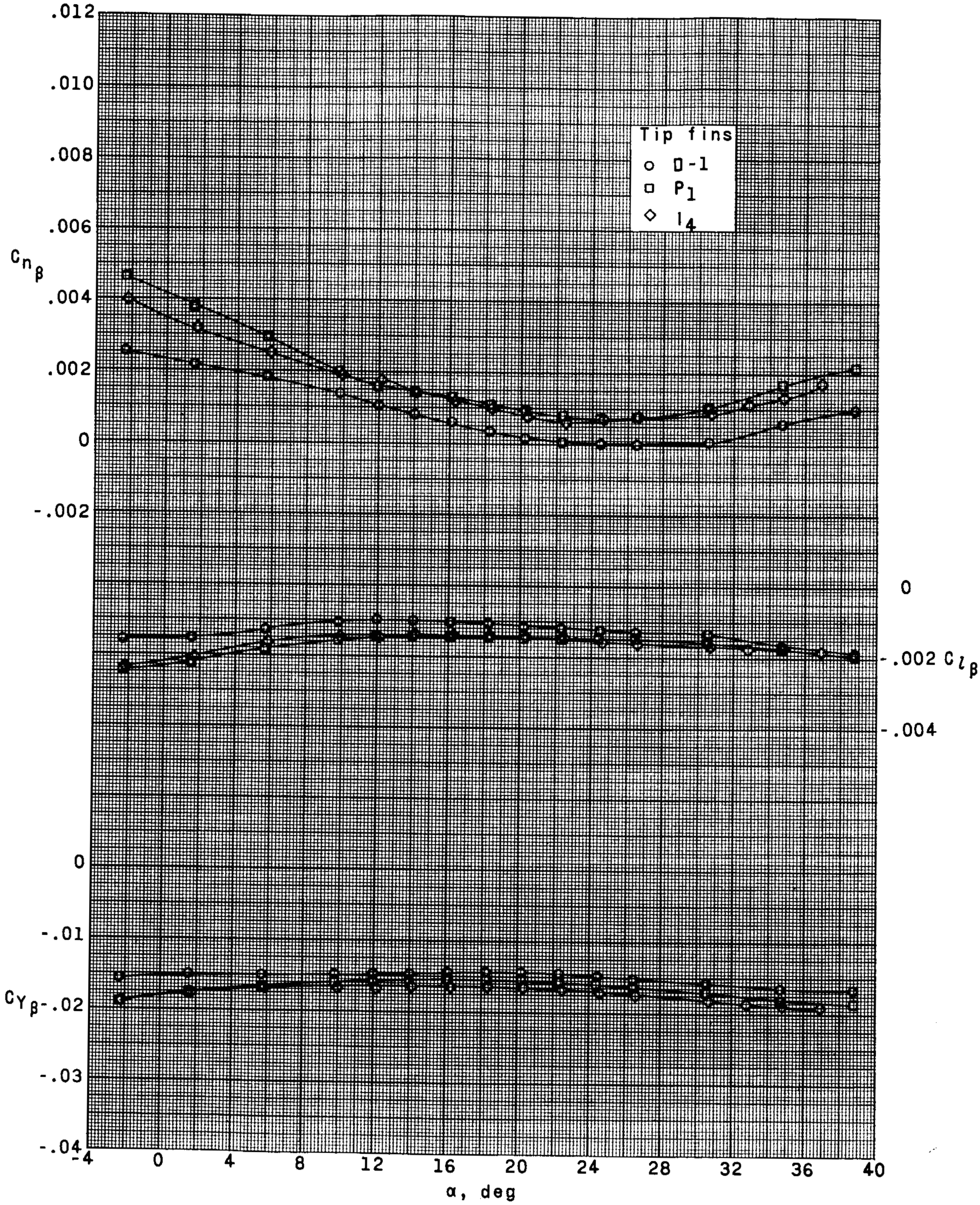
Figure 24.- Effects of tip fins D-1, P_1, and I_4 on lateral and directional stability derivatives of HL-10 with center fin E_2.

[redacted]



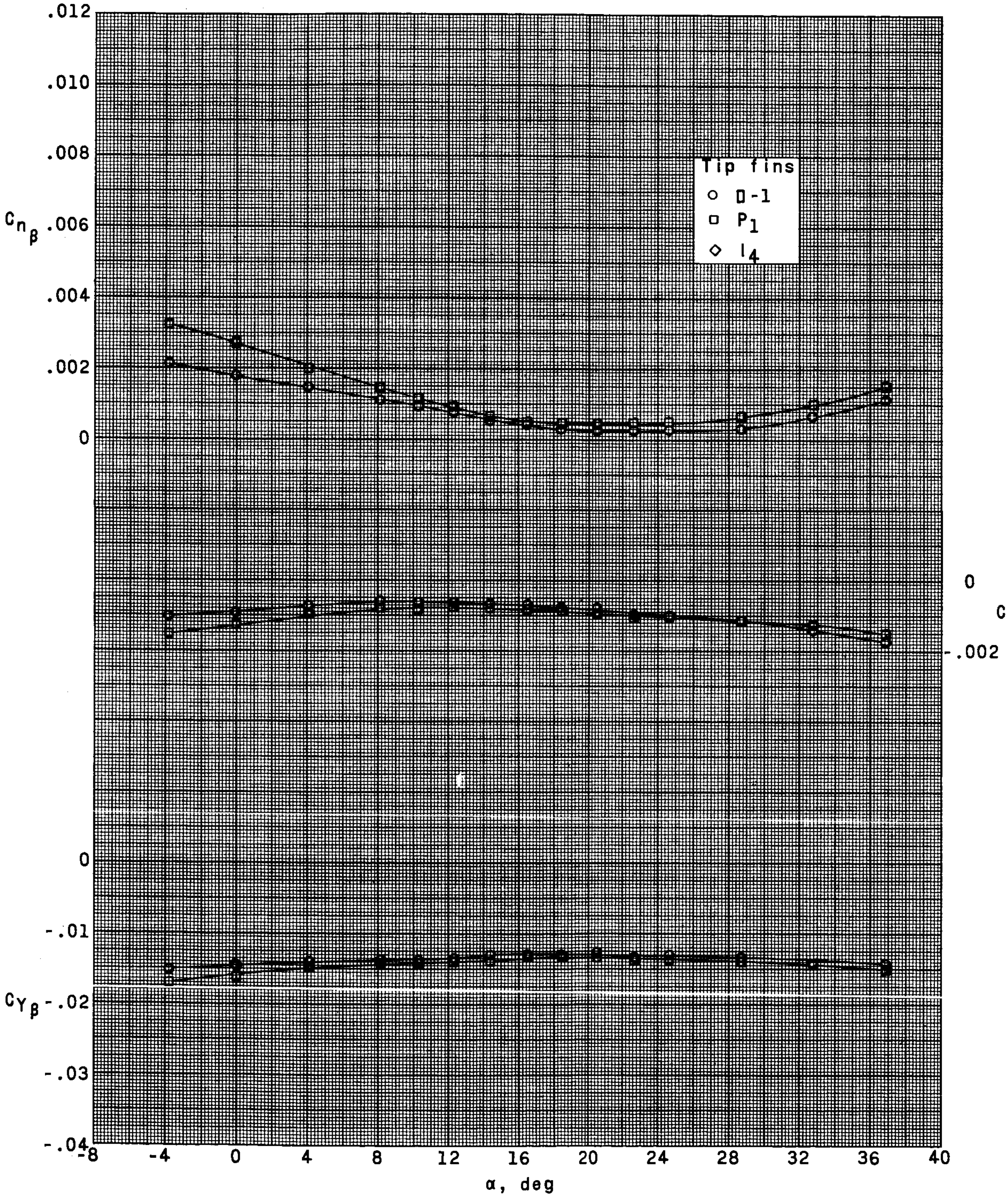
(b) M = 1.80.

Figure 24.- Continued.



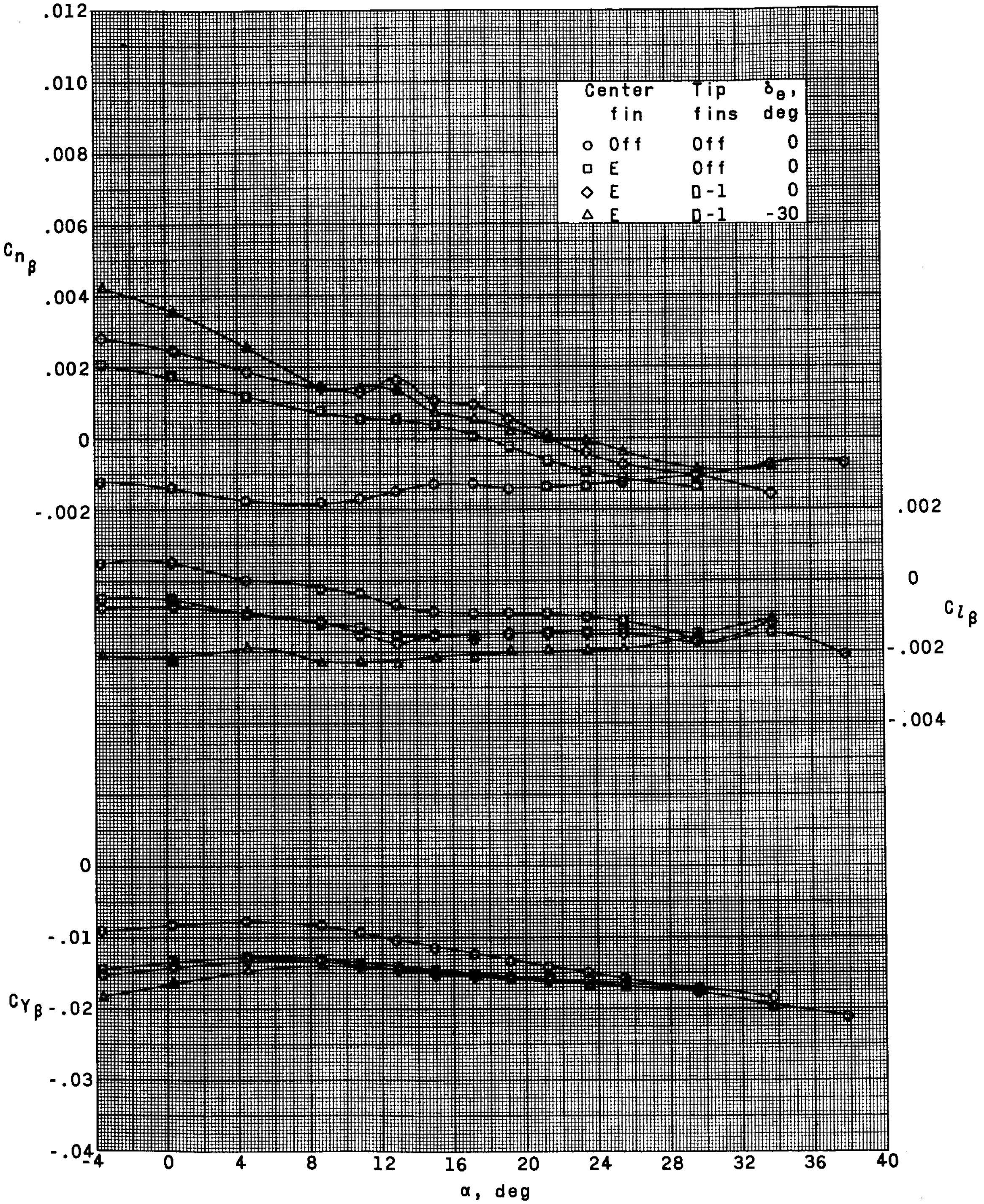
(c) M = 2.16.

Figure 24.- Continued.



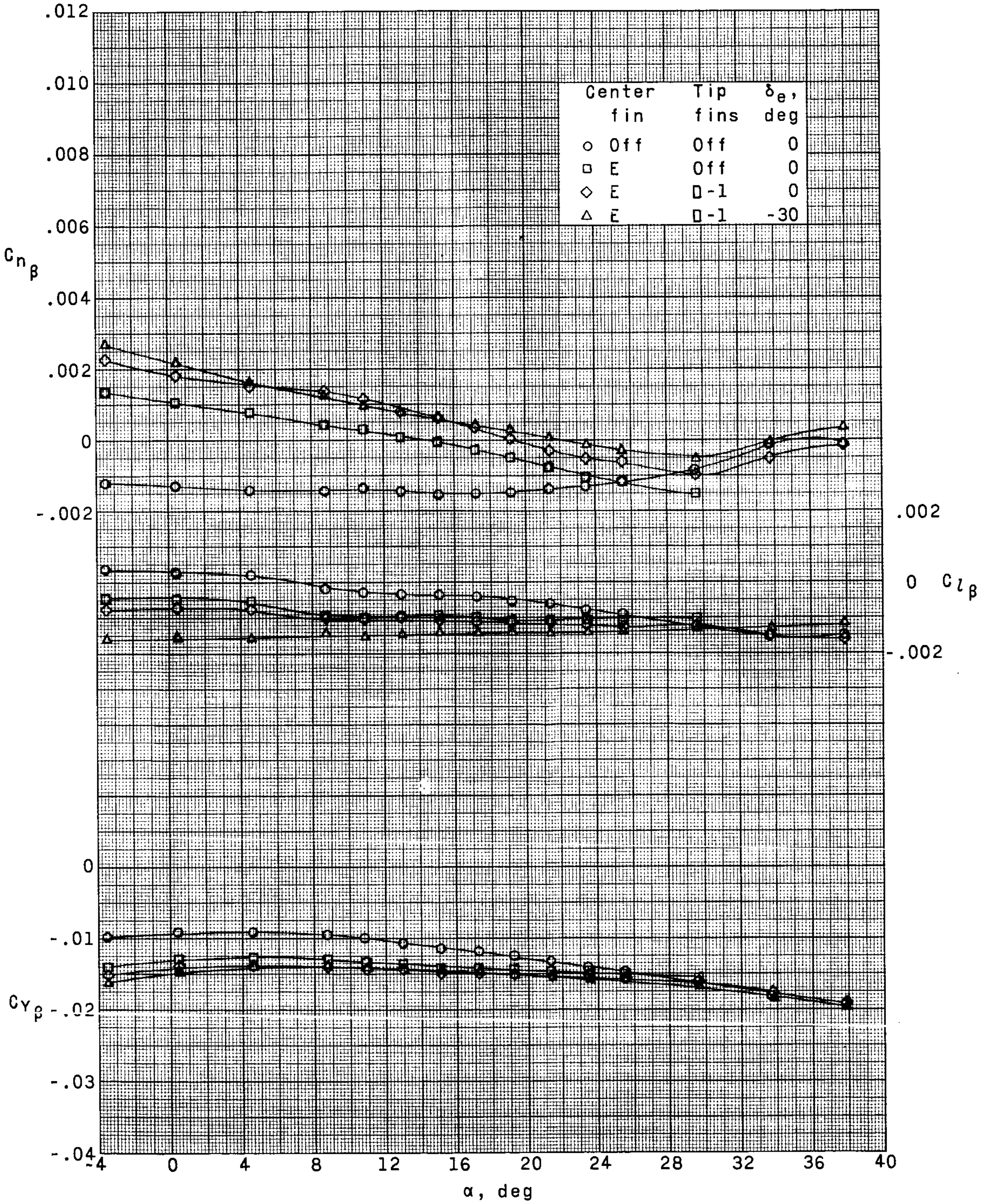
(d) M = 2.86.

Figure 24.- Concluded.



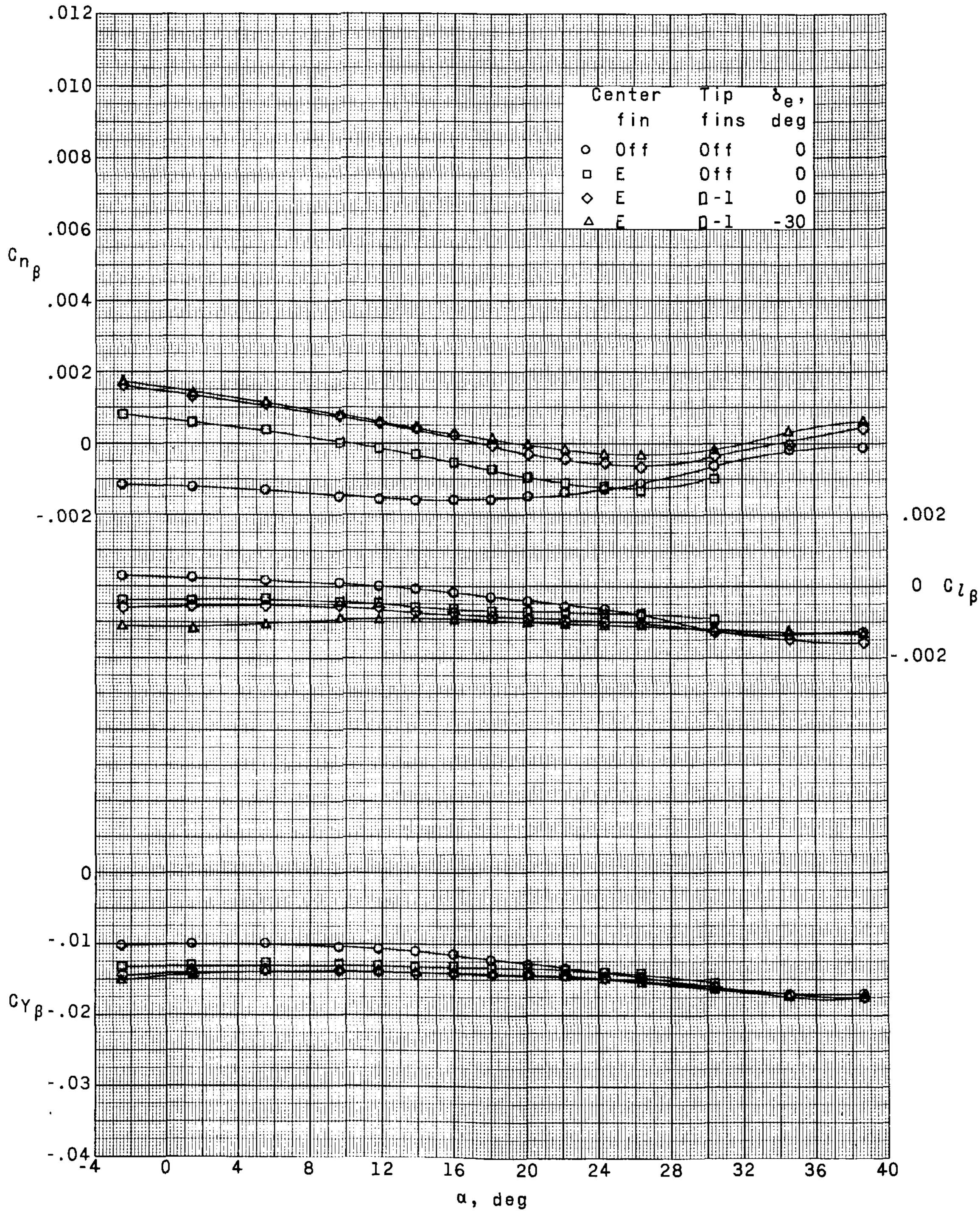
(a) M = 1.50.

Figure 25.- Effects of various configurations of HL-11 on lateral and directional stability derivatives.



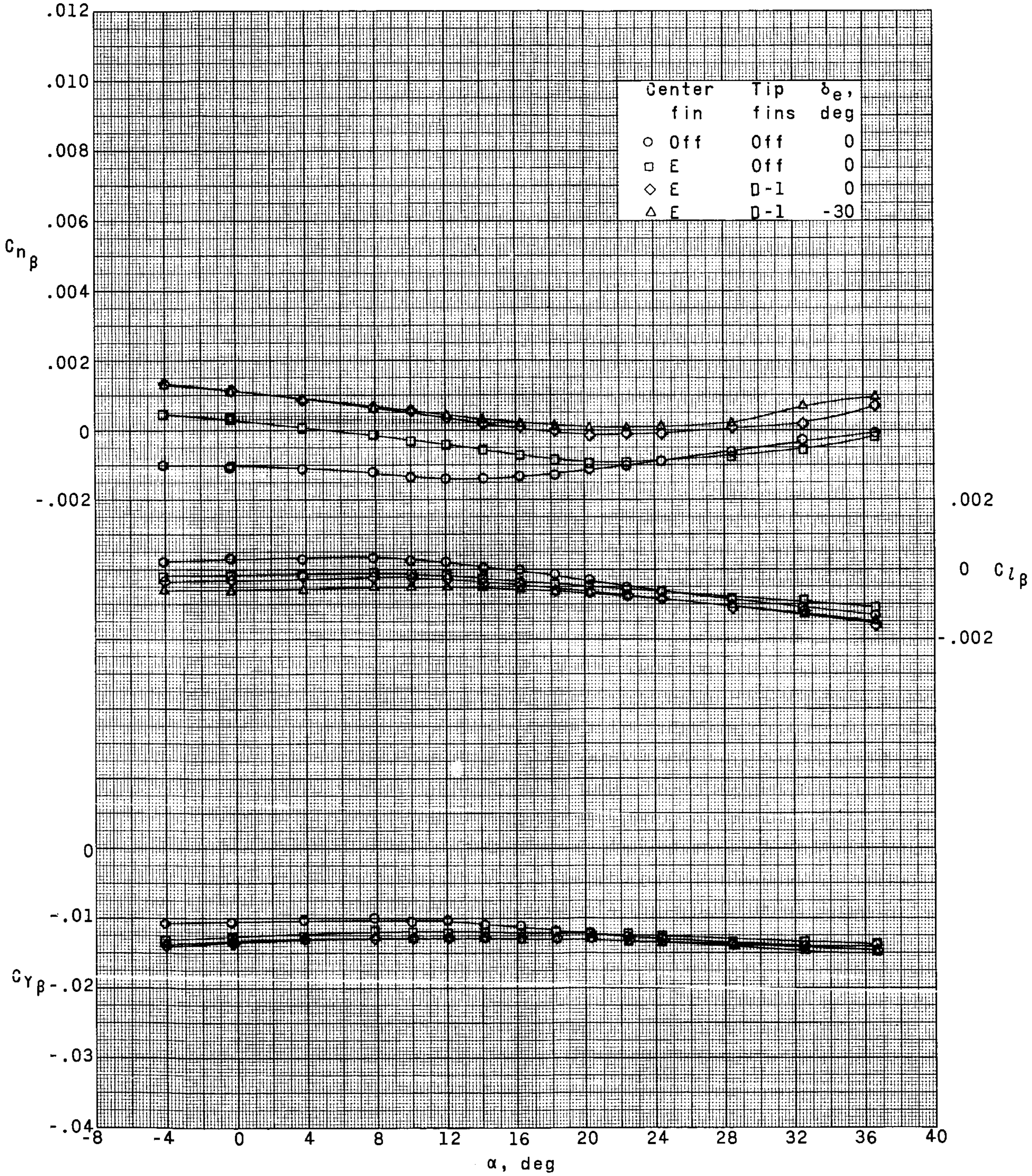
(b) M = 1.80.

Figure 25.- Continued.



(c) M = 2.16.

Figure 25.- Continued.



(d) M = 2.86.

Figure 25.- Concluded.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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